OUR PHYSICAL WORLD

—*Downing*

~~Goldie Dillon~~

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ELLIOT ROWLAND DOWNING

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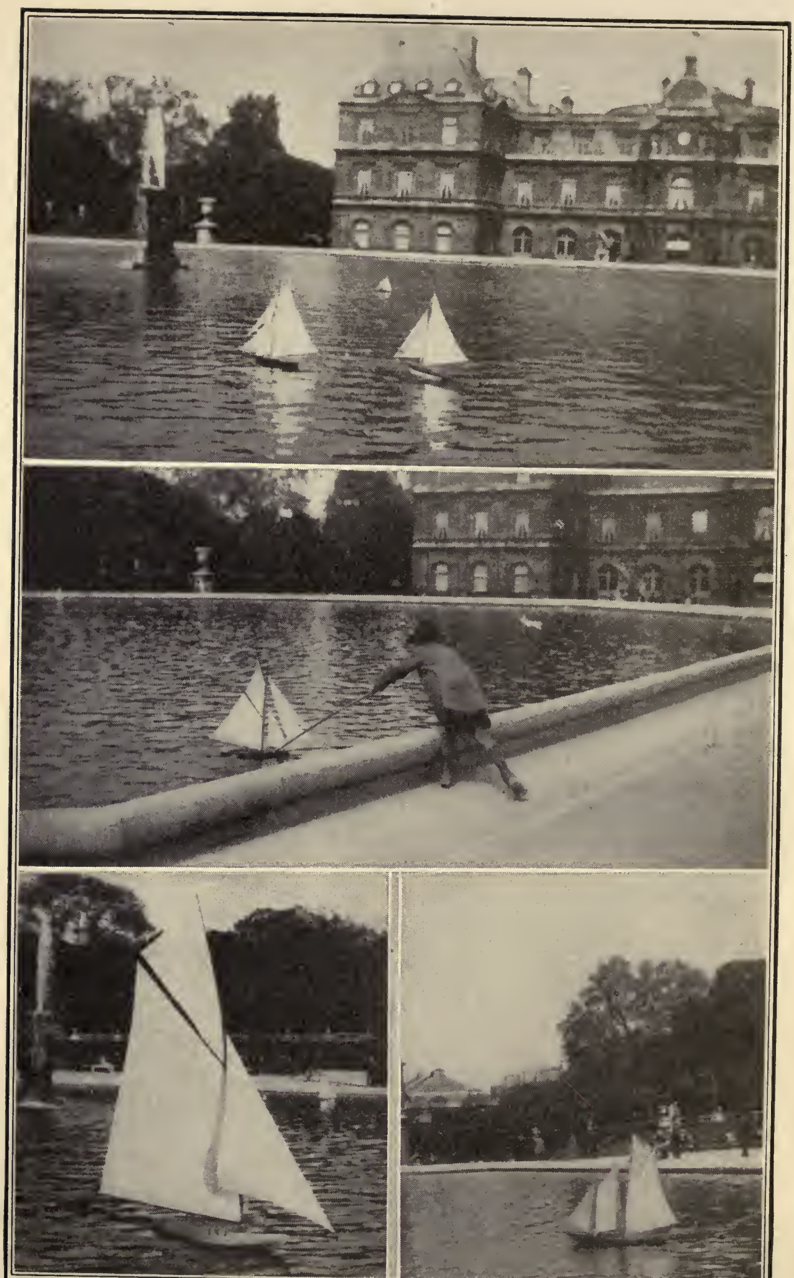

THE POND IN A CITY PARK WHERE CHILDREN RACE THEIR BOATS

OUR PHYSICAL WORLD

A Source Book of Physical Nature-Study

By

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WITH A CHAPTER ON RADIO COMMUNICATION
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GENERAL PREFACE

Never before in this country has there been so insistent a demand for a more thorough and more comprehensive system of instruction in practical science. Forced by recent events to compare our education with that of other nations, we have suddenly become aware of our negligence in this matter. Industrial and educational experts and commissions are united in demanding a change.

While on the whole there has been a steady increase in the amount of time given to science work in the secondary and elementary schools, the attention paid to it, especially in the elementary schools, has been somewhat spasmodic, and its administration has been more or less chaotic. This is not due to lack of interest on the part of school officials but to their dissatisfaction with the methods of instruction employed. There is no doubt that superintendents would gladly introduce more science if they felt sure that the educational results would be commensurate with the time expended. This is indicated by a recent survey of about one hundred and fifty cities in seven states of the Central West. The survey shows that two-thirds of them have nature-study in the elementary schools and that all are requiring some science for graduation from the high school. The average high school is offering three years of science. Since 1890 there has been a greater increase in the percentage of students enrolled in science in the high schools than in any other subject, and the present enrolment in science is greater than in any other subject. Moreover, greater attention is now being paid to the training of teachers in methods of presentation of science.

The chief needs in science instruction today are a more efficient organization of the course of study with a view to its socialization and practical application, and a clear-cut realization on the

part of the teacher of the aims, the principles of organization, and the methods of instruction; it is to meet these needs that this series is being issued. The books attempt to present such generalizations of science as the average pupil should carry away from his school experience and to organize them for the preparation of the teacher and for presentation to the class. The volumes are therefore of three kinds: (1) source books with accompanying field and laboratory guides for the use of teachers and students in normal schools and schools of education; (2) pupils' texts and notebooks; and (3) books on the teaching of the various science subjects. In the first the material is organized with special reference to the training of the teacher and the most effective methods of presenting the subject to students. In the second the matter is simplified, graded, and arranged in such a way that the books will serve as guides in science work for the pupils themselves. Moreover, they will furnish texts for the grades and high school that will simplify the teacher's task of presentation and will assure to the pupil well-tried and well-organized experiences with natural objects. This series of texts for elementary and secondary schools will have dependent continuity and the subject matter will gradually increase in difficulty to accord with the increasing capacity of the pupils. It will furnish a unified course in science. The third type of book is for the teacher and deals with the history, aims, principles of organization, and methods of instruction in the several sciences.

AUTHOR'S PREFACE

Among animals, play often functions to prepare for adult life. Wolf and dog puppies tussle in fun and so strengthen their muscles and improve their strategy for the fights of maturity. So the kitten plays with a stray spool or ball and goes through all the antics she will use later in catching her prey. The play activities of children are in many instances imitative of adult activities. Dolls are given as solicitous attention by the child as is the baby of the household by the parents. The plan of the play house built with blocks receives a deal of thought. The play store must have its wares appropriately displayed; clerk and purchaser must be properly decorous.

One need only go through the toy department of a city store to see that toys have followed the trend of a scientific age and are themselves replicas of adult appliances. There are construction sets, railroads and trains, telephones, radio sets, aeroplanes, magic lanterns, chemical sets. It seems a great opportunity with this interest in scientific toys to secure for the child through play a variety of experiences that will give him some elementary appreciation of those principles of science which are so important in the social and industrial life of the adult.

It is the purpose of this book to organize the subject-matter of elementary physical science or physical nature-study about toys and familiar home appliances. It is hoped it may serve as a guide in the workshop of the boy or girl who enjoys making things, that it may help children understand how commonplace appliances work and may aid parents and teachers in answering the questions of inquisitive youngsters. It is a source book in the sense that it brings together in one volume material elsewhere scattered and difficult of access. This volume is supplemented by the practical constructions in the *Field and Laboratory*

Guide in Physical Nature-Study already published. There are introduced into this book some things more profound than most grade children will undertake to understand. They are intended to serve as a background for parent and teacher in order that they may present the materials to the children in better perspective. They are suggested by the types of questions experience has shown are most frequently asked by those preparing to teach this subject-matter.

ELLIOT R. DOWNING

THE UNIVERSITY OF CHICAGO
THE SCHOOL OF EDUCATION
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CHAPTER I

THE UNIVERSE IN WHICH WE LIVE

Why does not someone teach me the constellations and make me at home in the starry heavens, which are always overhead and which I don't half know to this day.—CARLYLE.

Were you so fortunate as a child as to have some older companion—father, mother, big brother, or teacher—who took you out under the sparkling night sky and taught you to know the conspicuous stars by name, pointed out some of the constellations, and told you the marvelous myths connected with them that have come down from the childhood of the race to delight the modern child? Was the night a source of terror to you, or was it a source of pleasure because the stars had come to seem like old friends and you knew their names and some of the marvels of their existence? To how many a modern adult has the starry sky come to be so commonplace that he is unaware of its existence—perfectly oblivious to the glory of the heavens. If as a child you had a speaking acquaintance with the stars, if you knew them as distant suns, if you were made aware of their immensity and the immeasurable distance of these familiar yet usually unknown companions of the night, if you learned to recognize the wandering planets, then the infinity of the universe, the mystery, the awesomeness, made so deep an impression on your childhood imagination that the nightly pageant can never be commonplace. It seems as if some such impression should be one of the inalienable heritages of childhood.

The sun, the moon, the stars, and the other heavenly bodies have always been objects of great interest to man. Indeed, they have been objects of mystery, of reverence, and of worship. Primitive man recognized in the splendid sun the source of light, of comfort, and of life. The stars were his guides by night, the

moon, a welcome relief from the fearsome gloom. He was prone to identify all these things as the dwelling-places or the very incarnations of his gods, easily believing that they exerted a potent influence for good or evil over his daily life. So astronomy, or its earlier prototype, astrology, is the oldest of the natural sciences.

The early astrologers knew most of the planets, too, as brilliant bodies that are not fixed in their positions with relation to each other as are the stars, but are constantly changing their locations, apparently pursuing somewhat erratic courses among the stars. Indeed, the Greek word from which the name planet is derived means "a wanderer." The paths of these wandering bodies the ancients knew with remarkable accuracy and they even foretold their positions with certainty. The names of these bodies still indicate their identification with the ancient gods.

These planets we now know revolve about the sun. The earth is simply one of them. In order they are: Mercury, Venus, the earth, Mars, Jupiter, Saturn, Uranus, and Neptune. Mercury is nearest to the sun, Neptune the farthest. Uranus and Neptune were unknown to the ancients, for they are visible only with the aid of the telescope. Uranus was discovered by accident by Sir William Herschel in 1781, while he was making a systematic survey of all the stars. The size, motion, and position of Neptune were calculated before its discovery, for Uranus did not move as it should, and astronomers felt certain it must be influenced by some, as yet, undiscovered planet. Adams and Leverrier, respectively an English and a French astronomer, made the very difficult calculations to determine its position, and Galle, a German astronomer, was the first to see it, September 23, 1846.

Between the orbits of Mars and Jupiter there are more than 500 small bodies, similar to planets except for their size. They also revolve about the sun. These are known as planetoids. The first of them was discovered the first day of the nineteenth century by Piazzi at Palermo, Italy.

Naturally the most interesting, as it is the most conspicuous, of all the heavenly bodies is the sun; it has been worshiped as a diety by many primitive peoples. While astronomy has robbed it of its mysticism, it has increased our wonder at the marvels it displays. In the first place, it is tremendously large as compared to our earth, having a diameter of 866,540 miles, about 110 times that of the earth. More than 1,300,000 bodies the size of the earth could be packed into the space occupied by the sun. It is because of its enormous mass that the sun is the center of our solar system, holding the planets in their orbits by its gravitational pull.

The sun is the chief source of all of our energy—light, heat, and chemical rays emanating from it. We all realize from experience that the sun is the source of light and warmth. We know that its chemical rays produce marvelous changes in the photographic plate when a picture is taken. But few stop to think how very dependent we are on the sun in all our daily activities. It is the stored-up energy of the sun, caught and held by the plant, that is released from the wood we burn to keep us warm. Coal is compressed vegetation, the imprisoned sunlight of ages long gone by, so the heat that glows in our coal stove is really sunlight. Plants cannot live without sunlight, for its energy is the source of all their vital activities. It is this energy stored up in the plant in the form of sugar, starch, and other plant products that is released when we take these plant foods and burn them in our bodies, so that really we live on condensed sunshine. Even the meat we eat is that, too, for the source of animal energy is that of the plant. The electric light which we turn on in our homes is sunlight, for the electric current comes from a generator run by steam that is made by heat which in turn comes from the coal. Surely the sun is the immediate giver of all good gifts, and it is quite comprehensible that the savage should see in this life-giving orb the personification of divine power.

In spite of the fact that the sun does so much for the earth, warming its surface, providing energy for all life's processes and

for all industrial activities, still our little earth receives only a minute fraction of the power the sun is continually giving off, for the sun is radiating its energy, light, heat, and chemical influence in all directions. The earth is only a tiny sphere some 8,000 miles in diameter, nearly 93,000,000 miles from the sun. It, therefore, is hardly more than a speck compared with the sphere 186,000,000 miles in diameter which the sun fills with its energy. In fact, it is estimated that all the planets intercept only about one hundred millionth part of the sun's flood of power which is constantly pouring out into space.

Astronomers calculate that the sun gives off every hour as much radiant energy as would be produced by the burning in that time of a layer of hard coal 25 feet thick covering its entire surface. This is equivalent to 140,000 horse-power for every square yard of the sun's surface. If all the coal in Pennsylvania were mined and then burned in one second it would not produce as much energy as the earth receives from the sun in the same time. Such figures are almost beyond comprehension. It is well-nigh impossible to form any idea of the temperatures of the sun. It is believed that the outer radiating portion registers about 10,000° F., while the temperatures of the inner portions probably range above 50,000°.

But how can the sun remain so hot when it is spending its energy at such a profligate rate? It seems probable that one main source of its heat is the constant contraction that occurs in it. We know that when a body takes up heat it expands. A familiar example is the expansion of the mercury in the thermometer bulb as it gets hotter, which causes the mercury to rise in the tube. (See also experiment 94 in the *Field and Laboratory Guide in Physical Nature-Study*.) The reverse is also true, that when a body contracts it liberates heat. The sun is so very large that it is estimated it need only contract 250 feet in diameter a year to produce the energy it radiates into space. This is so slight an amount as to be immeasurable from the earth, except after the lapse of thousands of years. Quite probably, too, there

are sources of energy in the sun comparable to that of radium, which we know can give off energy rays for a very long time with scarcely an appreciable diminution of weight.

The outer layers of the sun, at least, are highly incandescent gases filled with liquid particles. Possibly the central portions are liquid. The intense heat makes volcanic activity and storms exceedingly violent on the sun. Explosions carry flames

FIG. 1.—The corona of the sun. Photographed at Matheson, Colorado, June 8, 1918, by Edison Pettit, of Yerkes Observatory.

out from its surface to a height of 200,000 miles or so, with velocities as great as 600 miles per second. Indeed, some of the impalpable dust and gases seem to be forced up to very much greater height, and appear as streamers running far out into space. These are seen well at times of eclipse, when the intense glare of the sun's surface is hidden behind the moon, and they form what is known as the corona (Fig. 1).

Storms are perpetually raging and the furious movements of the heated gases are seen even at our great distance. Sometimes the down draft of the cooler outer portions appears to pour through rifts in the gas mantle so swiftly as to cool off the fiery interior a bit, and then the throat of the cyclonic movement seems dark as seen against the brilliant deeper portions, and we

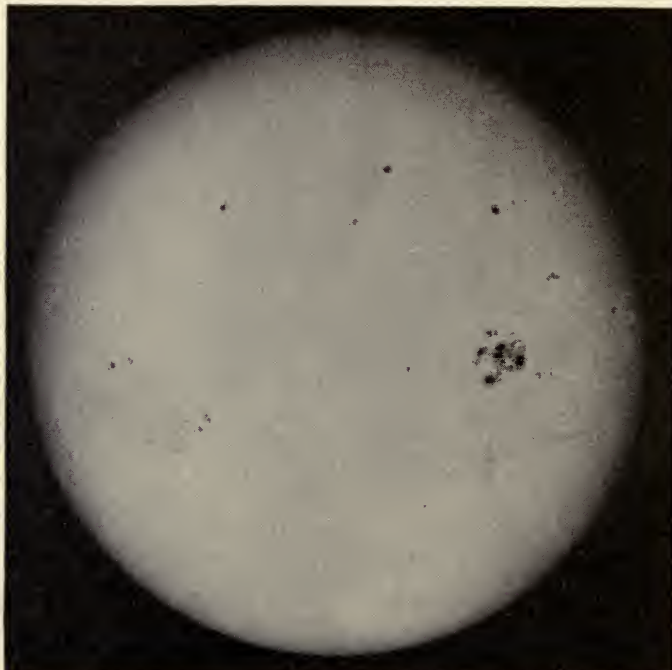


FIG. 2.—Sun spots. Photograph by Miss Mary Calvert, taken with the 12-inch telescope at Yerkes Observatory, August 7, 1917.

designate the object a sun spot (Fig. 2). Such spots are sometimes many thousands of miles in diameter, large enough to be seen through a smoked glass by the naked eye. They are of great interest since by watching them it was determined that the sun rotates on its axis from west to east once in about twenty-five days, a fact confirmed by other methods of observation. Their

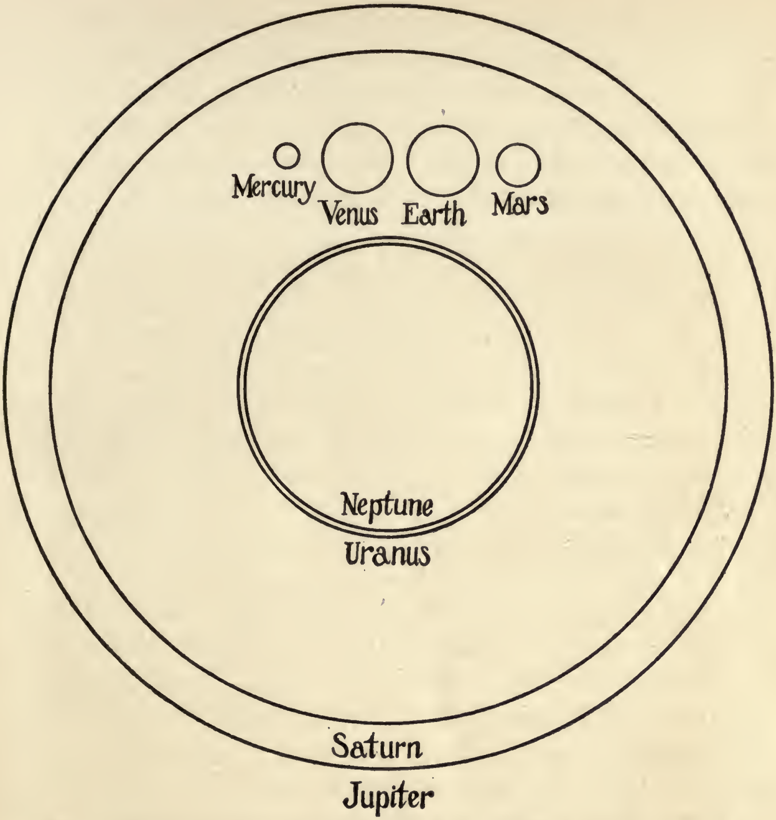


FIG. 3.—Diagram to show relative sizes of the planets. Drawn to scale

appearance seems to be coincident with electrical disturbances in the earth's atmosphere that affect our weather.

Our earth is by no means the largest of the planets, in fact it is a relatively small one. The equatorial diameters are given in the following table:

	Miles		Miles
Mercury	2,765	Jupiter	90,190
Venus	7,826	Saturn	79,470
Earth	7,913	Uranus	34,900
Mars	4,352	Neptune	32,900

These relative sizes are shown in the diagram by a series of circles drawn to scale (Fig. 3.)

Since Mercury and Venus are nearer the sun than is the earth, their orbits are included within that of the earth, and they can never appear on the opposite side of the earth from the sun, but are always seen near the sun, either rising just ahead of it, when they are called "morning stars," or setting shortly after it, when they are known as "evening stars." Mercury is as brilliant as its namesake, the liquid metal familiar in the thermometer bulb. Its orbit is so small that it is usually obscured by the sun's intense light, since it can never get far from it. Venus, however, with its larger orbit, may precede the sun or follow it at greater distance, and therefore is not commonly obliterated by the glare of the sun when it is a morning or evening star. Shining as it does with a silvery sheen, it has ever been a noted object in the sky, and may even be seen by day when one knows just where to look for it.

Mars glows with a ruddy light. Its blood-red appearance has always associated it with war. Mars was the war-god. While the surfaces of Mercury and Venus can never be studied with our telescopes very satisfactorily because they are so near the sun, Mars may be seen at times with a round disk, like a full moon; and since it is our next-door neighbor, distant when nearest to us only about half as far as the sun, its surface is plainly visible. What appear to be polar snow caps may be seen, which increase and decrease in size as the seasons change. Numerous straight markings radiate from the Pole in various directions, often intersecting. These have been thought by some astronomers to indicate a complicated system of canals built by the inhabitants of the planet to conduct water from the melting polar snows to irrigate their lands, or possibly since they change color seasonally they are lines of vegetation along such canals or along areas of maximum rainfall. Since Mars is much smaller than the earth, the force of gravity on its surface is only 38 per cent of that on the earth, so that an object weighing 100 pounds here would weigh only 38 pounds there. The inhabitants may grow, therefore, proportionately larger, and these giants might really dig such great canals, since the material excavated would be so

much lighter there than here. But this is all mere speculation even if it is fascinating. We know nothing about such inhabitants, or if there really be such.

We know even less about the four outer major planets than the minor ones, our near neighbors. Jupiter is some 1,300 times as large as the earth, and is probably still in a partly gaseous condition. Not long ago, astronomically speaking, it was glowing with its own heat, but now has largely cooled. Saturn has some unique rings about it, composed of myriads of tiny bodies that whirl about the planet in parallel orbits.

All the planets revolve about the sun in orbits that are practically circles, that of Neptune being most nearly such. The orbits are really ellipses, curves with one axis larger than the other. Such curves may readily be drawn thus: Take a 16-inch length of string and tie the ends together, making a loop. Stick two pins through the paper into the drawing board, 5 inches apart, and place the loop over the pins. Set the pencil point within the loop and hold the loop out taut, so the string forms a triangle with the pins at two corners, the pencil at the third. Now move the pencil about, as if trying to draw a circle, when an ellipse will be the result. The shape of the ellipse will vary as the distance between the pins is altered, or as the length of the loop of string is changed. The points occupied by the pins are known as the foci, and in the solar system the sun occupies one focus of each planetary orbit.

If the diameter of the orbit of Mercury be represented by a line 1 inch long, then that of Venus would be approximately 1.9 inches; of the earth, 2.6 inches; of Mars, 3.9 inches; of Jupiter, 13.4 inches; of Saturn, 24.6 inches; of Uranus, 49.5 inches; and of Neptune, 77.5 inches. In the case of the earth's orbit the difference between the long and short diameters is about 3,000,000 miles, not a great departure from a circle when it is remembered the total diameter is sixty times this.

The plane passed through the orbit of the earth is known as the plane of the ecliptic. If we should think, as did the

ancients, of the earth as floating, half-submerged, on a great sea and as moving about the sun, also floating, half-submerged, the surface of this sea would represent the plane of the ecliptic. The planes of the orbits of the other planets are all nearly in the plane of the ecliptic, that of Mercury being inclined to it at an angle of 7°, the others at much smaller angles.

The axis of the earth, the imaginary line on which it seems to rotate, so producing day and night (see diagram, Fig. 4), does

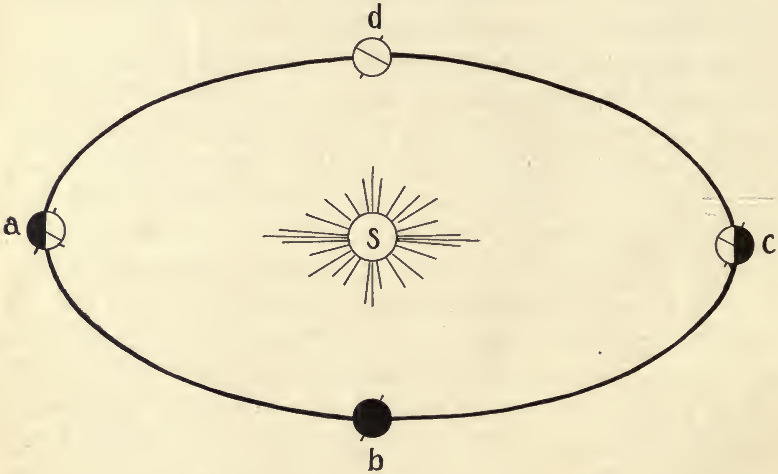


FIG. 4.—Diagram of the earth in four positions in its orbit about the sun. *a* and *c* the summer and winter solstices; *b* and *d*, the equinoxes. The relative sizes of the sun, the earth, and its orbit are necessarily incorrect.

not stand vertically to this plane of the ecliptic but is inclined to it at an angle of $23\frac{1}{2}$°. Note that the earth's axis is an imaginary line. The North Pole is not a real pole sticking up out of the earth. When Peary stood at the Pole there was nothing to mark the spot. If he had stood there long enough he would merely have turned about as one would if standing over the pivot of a turntable.

It is evident that at position *a* in the diagram the days are long and the nights short in latitude 40° in the Northern Hemi-

sphere, since such a place is in the illuminated part of the earth for a longer time than it is in the dark part. Moreover, the sun's rays strike the earth more nearly vertically in this latitude than they do in position *c*, and so they are more powerful. In position *a* there is summer in the Northern Hemisphere, for the long days give the sun time to impart more heat than is lost in the relatively short nights, and the nearly vertical rays are very effective, losing relatively little of their heat as they pass through the air.

In position *c*, however, the Northern Hemisphere is having winter, for the days are short and the nights are long, while the sun's rays strike the earth obliquely and so glance off readily; they lose much of their heating effect also, since they must pass through a long stretch of atmosphere that reflects much of their heat.

In positions *b* and *d* the circle between the dark and the illuminated sides passes through the North and South poles, and so the days and nights are of equal length all over the earth. These points of the earth's orbit are therefore known as the equinoxes. Points *a* and *c* are called respectively the summer and winter solstice, for the sun appears to cease its northward or southward journeying and to stand still for a few days before it begins to move back toward the celestial Equator.

Just as the planets travel in pathways about the sun, so there are bodies that we call moons, that travel in orbits about the planets. Our earth has one such, the queen of the night; Mercury and Venus, so far as we know, have none; Mars has two very small ones, probably not over 10 miles in diameter; Jupiter has seven, four large ones and three small; Saturn has ten, one of which is larger than the planet Mercury; Uranus has four and Neptune, one.

Our moon has been from time immemorial a god or goddess worshiped by primitive man. The Assyrians adored her as Ashtaroth; the Egyptians, as Isis; the Greeks named the moon-goddess Selene, or Phoebe and, later, Artemis, while the Romans called her Diana or Luna. The ancient Aztecs adored her as

Meztli, and regarded her as the wife of the sun-god. The son of this pair was Inca, their national hero.

Our moon is not very far away as astronomical distances go, only 238,840 miles. It has a diameter of 2,162 miles. The moon has no atmosphere and apparently no moisture on its surface. It is quite thoroughly cooled off, and the surface temperatures there are probably 200° below zero, except as the sun's rays heat it at noonday. Its contour is varied with great plains that are quite smooth and seem dark, and with mountainous areas whose numerous peaks reflect the light and so appear bright, just as the numerous facets of salt or snow crystals reflect the light and appear white. These patches of light and dark are arranged so as to suggest the face of the "man in the moon" or the "woman's face," according to the way one looks at it.

These imaginary figures have given rise to many fables. According to the Chinese legend, it is the man in the moon who ties together with invisible yet unbreakable cords the young man and maiden who are destined to marry each other. It has been aptly suggested that he must be the man of the honeymoon.

The moon shines only by reflected light, the sunlight always illuminating the half turned toward it. When the moon is on the opposite side of the earth from the sun we see the illuminated half, and the moon is full. The full moon, therefore, always rises as the sun is setting. When the sun and moon are on the same side of the earth and about in line with it, we do not see the moon at all, for the side turned our way is the dark side. Between these two positions we see first the new moon, just as a narrow rim of light, then more and more of the illuminated portion, as the moon proceeds to quarter and on to full. During this time it is waxing more and more brilliant. Then gradually it wanes, passing to third quarter and so on till the old moon disappears.

The period of time occupied by these changes from new moon to new moon is apparently the original month. The division of this into four periods or weeks was likely facilitated by

the easy recognition of the new moon, the first quarter, the full moon or second quarter, and the third quarter.

The ancients classed the sun and moon as planets, for they, like the true planets which they knew, Mercury, Venus, Mars, Jupiter, and Saturn, seemed to move about among the stars. The names of the seven days of the week were given in honor of these seven planets. Sunday, Monday, and Saturday are evidently names from sun, moon, and Saturn. The French names for the other days of the week show plainly their derivation from the Greek or Latin gods. *Mardi* is Tuesday; *mercredi*, Wednesday; *jeudi*, a contraction of *Jovis dies*, is Thursday; and *vendredi* is Friday. Our English names have come to us through the substitution of the corresponding Norse deities, Tyr's or Tiwes' day, Woden's day, Thor's day, Freya's day. Thus we are reminded daily of the old myths that were blended with the early astronomical lore.

The moon exerts two very potent influences on the earth. It is the chief cause both of the tides and of the precession of the equinoxes. The sun is only a secondary cause, for, though it is immeasurably larger, its greater distance makes it play the minor rôle. We say that the moon revolves about the earth. As a matter of fact, earth and moon revolve about a point that is relatively near the earth's center. It is as if we should balance on a point a rod with a large and very heavy ball at one end and a small light one at the other (see Fig. 5, p. 14), then set it to whirling. The small ball would move about the big one, but still the big one would travel in a circular path about the balancing point. So the earth constantly moves straight ahead and at the same time toward the moon, making a nearly circular path around the center of gravity of the pair. This path is not jerky as indicated in the diagram, where first one movement is shown and then the other, but quite smooth, since both movements occur simultaneously. Now, that part of the ocean near the moon moves toward the moon most rapidly, the solid earth next most rapidly, and the waters on the side opposite the moon least rapidly, since the pull

of gravity varies inversely as the square of the distance. So there is a heap of water in the ocean under the moon and one on the opposite side of the earth also. When the earth revolves, the solid land slips along through the water thus held by the moon, the water level along the shore rises, and we say the tide is coming in. As the shore passes out at the other side of the heap the tide falls; so the tide rises and falls twice a day. When the sun assists the moon, as it does when the moon is full or new, the tides are highest. If sun and moon pull against each other, as they do when the moon is at the quarter, the tides are slight. The

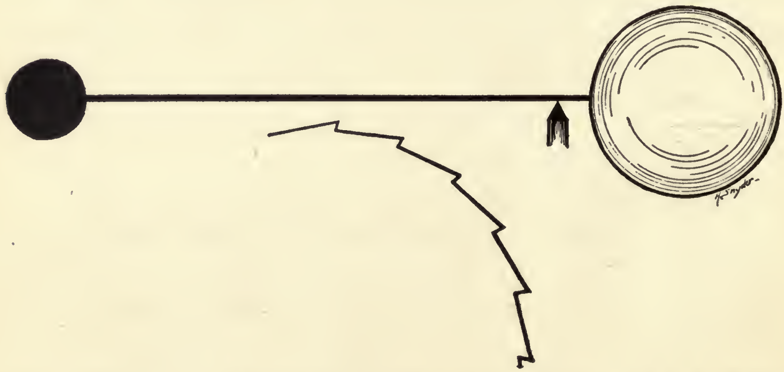


FIG. 5.—Diagram of a portion of the earth's path to show the cause of the tides

amount of the rise or fall of the tide is not great on the open coasts, but when the tide runs up a narrowing bay the rise and fall near the head of the bay may be 60 to 70 feet.

The friction of the land sliding along under these heaps of water slowly retards the rotation of the earth on its axis and in time must check it. It is supposed that the moon once possessed oceans, and the tides occasioned by the earth's attraction caused its rotation to slow down until now its period of rotation is the same as its time of revolution about the earth, and therefore it keeps the same face always toward us. Its waters have since combined with its mineral materials to form the hydrated minerals (see p. 58).

The second effect the moon produces on the earth is the precession of the equinoxes. The sun again plays the minor rôle. The earth is a sphere with an added bulge about the equatorial regions (an oblate spheroid—see Fig. 6*A*). The moon's orbit is inclined to the plane of the ecliptic only 5°, so the sun and moon are pulling on the earth practically in the same plane. Since the earth's axis is inclined $23\frac{1}{2}°$, this equatorial bulge is in large

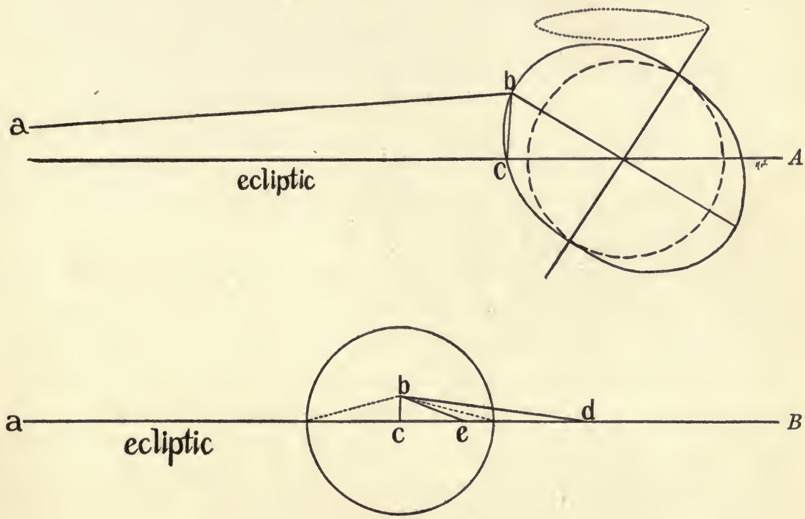


FIG. 6.—(*A*) Diagram showing the earth's equatorial bulge and its action in causing the precession of the equinoxes; (*B*) diagram showing the effect of the moon's attraction on the motion of the earth.

measure above or below the plane of the ecliptic. Therefore, the sun and moon tend to pull the bulge back into the plane; that is, the pull of the moon (and sun) acting on the bulge along the line *a–b* is resolved into two forces, one component acting along *b–c*. Points along the Equator such as *b* (Fig. 6*B*) are therefore under the stress of two forces, one *bc*, this pull toward the plane of the ecliptic, the other, the momentum of the earth's rotation indicated by *bd*, the resultant being a motion along, say, *be;* that is, a point on the Equator at every turn of the earth

cuts the ecliptic a trifle before it would if this pull of the moon were not acting on the bulge.

It is evident, then, that the equinoctial point is ever occurring a trifle earlier than it would occur if it were not for this action of moon and sun. This phenomenon is known as the precession of the equinoxes. As a result, the North Pole of the earth's axis does not point continually to the same spot in the celestial sphere, but makes a rotation once in 25,868 years. As a matter of fact, the motion is not as simple as described, for the moon, sun, and earth are constantly changing their relative positions, so it is quite irregular, though entirely predictable when the movements and consequent relations of the three bodies are known. It is a matter of relatively simple calculation to determine the point in the sky to which the Pole pointed thousands of years ago or will point in the future.

Some authorities claim that when the great pyramid at Cheops, Egypt, was built it was so oriented that a narrow passageway over 300 feet long pointed to the star that was then the polestar, alpha of the constellation Draco. This pyramid was located quite exactly on 30° north latitude. Certain of its dimensions apparently record the length of the year, the period of the precession of the equinoxes, and other astronomical data, so that it really is a record of quite wonderful astronomical knowledge on the part of its builders.

As one looks up into the starry skies on any clear night, it seems as if the stars were as numerous as the sand grains on the seashore. Yet, as a matter of fact, there are only about 2,000 visible to the average eye at any one time. And even if you should watch the heavens year in and year out from points both north and south of the Equator, you would see only 4,000 to 6,000. These stars differ in brilliancy from the brightest one, Sirius, down to those that are just visible to the naked eye. They are consequently said to differ in magnitude, sixth-magnitude stars being those that are only just visible, first-magnitude stars those that are most brilliant. This latter group

has recently been subdivided into three magnitudes, as our measures of brilliancy have become more exact, namely, stars of -1 magnitude, the most brilliant, those of magnitude 0, and those of magnitude 1. A star of magnitude 1 is 2.5 times as bright as one of magnitude 2, $(2.5)^2$ or 6.25 times as bright as one of magnitude 3, etc.

But the stars that are visible to the naked eye are but a fraction of those that exist. The telescope shows thousands and thousands that the eye cannot see. Indeed, every time a new and more powerful telescope is made and pointed to the skies it shows new stars beyond the range of the old, less powerful telescopes; so that just how many stars there really are no one knows. Some 200,000 have already been located and mapped, and it is estimated that there are at least a half-billion of them in our stellar system. The Milky Way, which seems like a band of hazy light crossing the sky, is made of thousands of stars so numerous and so distant that their radiance blends into a mist of light. Then beyond the limits of our galaxy of stars, with its half-billion or more, are possibly many other galaxies, so distant they seem like mere flecks of hazy light, even when seen in powerful telescopes. How many such exist astronomers even do not guess.

Many of these stars are almost inconceivably distant from our earth. The nearest one, 61 in the constellation of Cygnus (see p. 29), is so far away that, if we represent the distance from the earth to the sun by 1 inch, the distance to this star would be represented by a line $7\frac{1}{2}$ miles long. Light traveling at the enormous rate of 186,300 miles (seven and one-half times around the earth) in one second, takes three and one-half years to reach us from this star. Some of the stars are so far away that their light only reaches the earth after traveling through space for 10,000 years, and that probably is not the limit.

Stars are really suns that in all probability, judging by our sun, have planets revolving about them. Is it possible they too are inhabited? If so, by what sorts of beings? And many of

these distant suns we call stars are very much larger than ours. Betelgeuse in the constellation Orion (p. 33) has been recently measured and found to have a diameter 300 times that of our sun, yet it is so far away it is not as brilliant as Sirius, which, though only thirty times as large as our sun, is but eight and one-half light-years away and outshines Betelgeuse.

There are only about twenty-five stars in the list of the old first-magnitude stars, so it is not very difficult to learn to locate and recognize these. They were all known to the ancients and came down to us with ancient names.

Undoubtedly the stars served early man as a means of keeping his directions when traveling by night, as they still similarly serve us. The stars, too, were supposed to mark important events. Thus, Sirius, the Dog Star, when it received its name, rose just before the sun, at the time of the year that was intensely hot, when dogs went mad, and so it appeared as a warning of the approach of the season that must have had terrors for the early hunter and shepherd peoples among whom dogs were likely as abundant and as ill kept as they are today in the East.

Probably, too, important events in the history of the race were connected with groups of stars, as well as with individual stars, when such groups were particularly brilliant or in commanding positions at the time such events occurred, just as the birth of Christ was connected with an unusual astronomical phenomenon, the appearance of the "Star in the East." Many of the star groups or constellations are still commemorative of events that once had great historical significance, but the stories have been so altered by constant repetition, as they have been told and retold, that they come to us merely as legends, or myths. Many of these legends have been transmitted from the earlier primitive peoples through the fervid imaginations of the Greeks, and so the heavens have come to be "a pictured scroll of Greek mythology." One needs a large measure of this imaginative power to see in the star-groups any likeness to the things the ancients figured in their maps of the sky.

In latitudes such as those of mid-Illinois, Indiana, and Ohio, or of Washington, D.C., or Denver, Colorado, all in the neighborhood of 40° north latitude, the point directly overhead in the celestial sphere, the zenith, is evidently 40° north of the celestial Equator and 50° from the North (celestial) Pole. The Pole is, in this latitude, about 40° above the horizon. There is, therefore, a region of 40° around the Pole in which the stars never set. There will be a broad band of sky running from 50° north of the celestial Equator to 50° south that will be in part above the horizon at any one time, and all of which may be seen by continuous observation throughout the year or through any winter night.

It is evident that the constellations seen, say, at midnight on December 20 are not the same as those visible at the same hour on June 20, for at the first of these dates the dark or night side of the earth (Fig. 4, position *c*) is turned toward one part of the starry vault, while at the other date it is turned toward the opposite portion. Since the earth rotates on its axis, a person at latitude 40° north will see all the stars pass in view that are located north of 50° south celestial latitude.

Probably the one constellation that everyone knows is the "Big Dipper," seen in the latitude mentioned at any time of the night, for it never sets but simply circles about the celestial Pole. All the stars that make the Dipper are quite bright (see Fig. 7, p. 20). The Dipper makes up part of the constellation known as the Great Bear (Ursa Major). It is a curious fact that widely separated ancient races like the Chaldeans (Abraham, it will be remembered, came from Ur of the Chaldees) and the American Indians called this star group by the same name, the Great Bear. This is true of many constellations. They bear the same name among Chaldeans, Chinese, Egyptians, Greeks, American Indians, etc. It seems as if the name of many constellations must have been given them before the races separated from that region that was their common home.

The two stars forming the side of the Dipper away from the handle are commonly called the pointers, for if the line drawn

through them is extended toward the Pole it leads to Polaris, now the polestar, situated not exactly at the North Pole but very near it. This star is at the end of the handle of the Little Dipper, which is made up of rather faint stars so that it is visible only on very clear nights. The Little Dipper is included in the figure of the Little Bear. The star in the middle of the handle of the Big Dipper is an interesting double, both stars of which are

FIG. 7.—Ursa Major, the Big Bear

visible to the naked eye. They are named Mizar and Alcor, the Horse and Rider.

If the curved line made by the stars of the handle of the Big Dipper be extended for about the length of the Dipper, handle and all, it leads to a star of the first magnitude, Arcturus, 70° from the Pole, and this locates Boötes the Hunter, who is following the Bears (Fig. 8). North of Arcturus and somewhat to the east is a kite-shaped figure that is also included in Boötes.

The Greek myth of these constellations is as follows: Callisto was so beautiful that she excited the jealousy of Juno, the goddess, who changed her into a bear. While wandering in the woods she met her son Arcos, who was about to strike her with

Fig. 8.—Boötes, the Hunter

his spear, when Jupiter in pity snatched both up to the sky, and there they still are, the Big and Little Bears.

The Fox Indians believed the forest trees wandered about and gossiped among themselves at night. Once a bear clumsily bumped against the oak, king of trees, in his wanderings. The

king, in anger, seized the bear by his short tail and so threw him into the sky, stretching his tail in the process. Hence this bear now has a long tail, an appendage quite foreign to his kind. In the earlier star maps, the bear is figured without a tail, but in later maps both Big and Little Bears possess tails.

Ursa Major is also figured, especially in England, as a wagon, Charlemagne's cart or Charles's wain, and Boötes is then the wagoner. Since the wagon turns about the polestar like the hand of a clock on a great dial, its position was an index of time to those familiar with it. So Shakespeare makes the Carrier say in Act II, Scene 1, of *Henry IV:* "Heigh-ho! An't be not four by the day, I'll be hanged; Charles' wain is over the new chimney and yet our horses not packed."

The constellation of the Little Bear was also known to the ancients as "Transmountain," "beyond the mountain," for they believed that the earth rested on the "mountain of the north" and that beyond it the gods had their habitation. This idea is evident in such biblical passages as Isa. 14:13 and Ps. 48:2. The polestar in Transmountain is probably the most famous single star in the sky. Shakespeare in Act III, Scene 1, of *Julius Caesar* makes Caesar say:

> But I am constant as the northern star,
> Of whose true-fixed and resting quality
> There is no fellow in the firmament.
> The skies are painted with unnumbered sparks;
> They are all fire, and every one doth shine:
> But there's but one in all doth hold his place.

On the opposite side of the Pole from the Big Dipper is a group of fairly brilliant stars forming an open *W* or *M* that readily serves to locate the constellation Cassiopeia (Fig. 9). Together with one rather dim star the letter makes the figure of a chair and is known as Cassiopeia's Chair, and on it the unfortunate queen is seated in the ancient star charts. The other dramatis per-

sonae of this legend are also close about the Pole, and we may use the stars of the Chair to find them.

Fig. 9.—Cassiopeia

Key to star magnitudes in this and succeeding figures, except Fig. 11

A line drawn through alpha and beta Cassiopeia, which stars form the ends of the legs of the Chair (see Fig. 10, p. 24) and extended about once and a half the length of the whole Chair,

leads to the star alpha of Cepheus, the King (Fig. 11). Directly in line from this toward Polaris is another star of the figure, so that these stars may be used as pointers to the Pole quite as well as the two of the Big Dipper. A third fairly bright star of Cepheus may be located from the sketch.

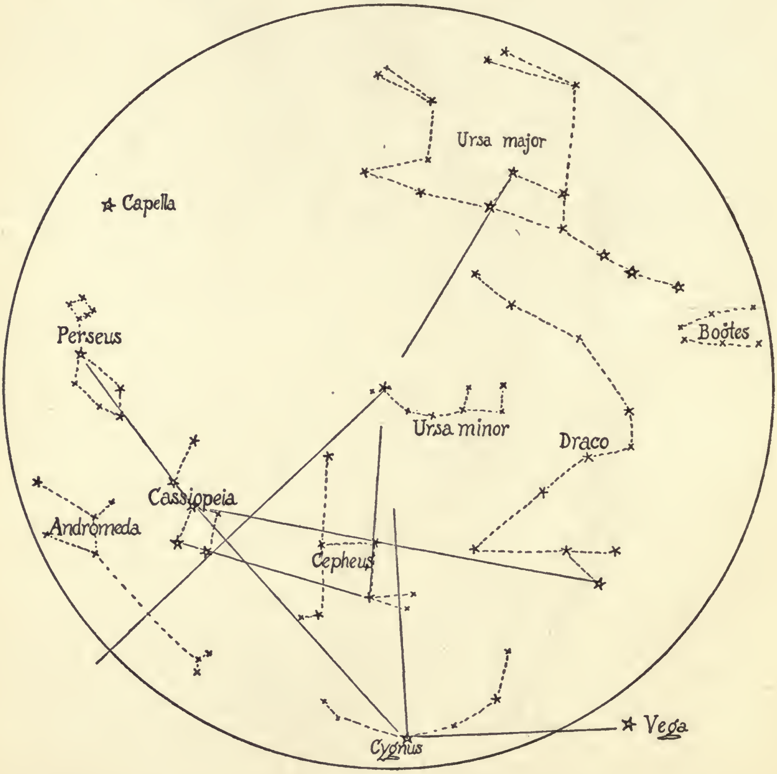


FIG. 10.—The chief constellations about the Pole and the pointers to be used in finding them.

Carry a line through the lower two stars of the Chair back, in the opposite direction from Cepheus and about as far from Cassiopeia as Cepheus is, and there is seen a conspicuous star alpha in Perseus, the hero of the tale. This same star is found by passing a line through the one in the tip of the Dipper and the

basal star near the handle; alpha Perseus is about as far from the Pole as is the latter star. Almost in line with alpha Perseus but farther away from the Pole is another bright star of Perseus, Algol.

Now alpha Cassiopeia, alpha Perseus, and a fairly bright star of Andromeda make an equilateral triangle; so Andromeda

FIG. 11.—Cepheus

can be located. The other moderately bright stars of this constellation are seen in Figure 12 (p. 26). If the line through the pointers of the Dipper be carried beyond Polaris about twice as far from the latter as are the pointers, it leads to a large figure of four bright stars known as the square of Pegasus (Fig. 13, p. 27). One of them is really in the figure of Andromeda.

The villain of the piece is the Dragon (Fig. 14, p. 28). Draw a line from the basal star in the back of Cassiopeia's Chair through

that polestar pointer in Cepheus nearest the Pole, and carry it beyond Cepheus about as far as Cassiopeia is from Cepheus and it reaches the head of the Dragon marked by four stars, the two bright ones being the eyes. This same Dragon's Head is found also by carrying a line through the two stars on the opposite

Fig. 12.—Andromeda

side of the bowl of the Big Dipper from the polar pointers. The body of the Dragon is traced in a curving line of fainter stars that lie between the Big and Little Bears. If the planisphere (see Figs. 194 and 195 inserted at end of this volume) is constructed and used, it will help locate these and the other constellations.

Cepheus and Cassiopeia were the king and queen of Ethiopia. The queen was very beautiful but also very vain—so much so that she had the temerity to compare herself to the sea nymphs. This so enraged them that they sent a monster of frightful mien to ravage the coasts of the kingdom. The king and queen were informed by the oracle that the only way to stop its awful visitations was to chain their daughter Andromeda to the rocks and

Fig. 13.—Pegasus

allow the monster to have her; so Andromeda was prepared for the sacrifice. Perseus was just then returning on his famous charger Pegasus from his great adventure, during which he slew the Gorgon and brought back its head. He saw the beautiful Andromeda chained to the rock, slew the dragon, and so won her for his bride.

If the same two stars in the back of Cassiopeia's Chair that were used to point to Perseus be again used as pointers, but the

line *bc* extended through them in the opposite direction from Perseus and about as far again from Cassiopeia as is Perseus, a very bright star is encountered, Deneb, in the constellation of Cygnus, the Swan (Fig 15). The chief stars of this constellation are shown in the figure, and it is to be noted that some of them are arranged in the form of a cross, so that the group is sometimes known as the Northern Cross. Cygnus, or more correctly,

FIG. 14.—Draco, the Dragon

Cyncnus, the Swan, is the son of Mars and the most intimate friend of Phaethon. Phaethon was the son of Phoebus, who drove the chariot of the sun. He persuaded his father to let him drive for one day. The steeds, feeling the strange driver, ran away, bringing the sun so close to the earth as to scorch it. Jove struck Phaethon with a thunderbolt, and he fell into the river Eridanus (p. 40). Cygnus lingered at the spot, repeatedly plunging beneath the flood to seek some relic of his lost com-

panion. The gods, angered, changed him to a swan that nightly plunges into the sea.

The line drawn through the two stars of the bowl of the Dipper opposite the polestar pointers not only reaches the head of the Dragon, but if extended a bit farther reaches a first-magnitude star, Vega, in the constellation of the Lyre. The polestar, Deneb, and Vega mark the corners of a right triangle. The posi-

FIG. 15.—Cygnus, the Swan

tion of alpha in the constellation of the Dragon with reference to this triangle of Polaris, Deneb, and Vega is shown in the diagram. If now this line through alpha Draco and Polaris is extended on the other side of the Pole about the same distance from the Pole as is the Dragon's Head, another first-magnitude star is seen, Capella of the Charioteer (Fig. 16, p. 30). Auriga is the Charioteer, who carried the goat, Capella, and the kids or Haedi in his arms. It was the goat that suckled the infant Jupiter. Having broken off one of his horns in play, Jupiter endowed it

with the power of being filled with whatever its possessor might desire, whence it was called the horn of plenty or cornucopia. These kids were supposed to be a very unpropitious sign.

> Tempt not the winds, forewarned of dangers nigh,
> When the Kids glitter in the western sky.
>
> —CALLIMACHUS, third century, B.C.

FIG. 16.—Auriga, the Charioteer

About 9:30 Christmas night or 7:30 a month later, the Pleiades are on the meridian not far north of the zenith. This group of stars is likely as well known as the Big Dipper. There are six or seven stars visible to the naked eye, grouped somewhat as a Little Dipper. Six stars are plainly visible, the seventh only to very good eyes. The one dim star was long ago very much brighter, so the cluster is also known as the "Seven

Sisters." The lost one, "Electra," is supposed to have run off to the Great Bear and is now Alcor. Many more are visible with a telescope and they are then seen to be enveloped in a great nebula so they "glitter like a swarm of fireflies tangled in a silver braid" (Tennyson). Onondaga Indians have a legend that the Pleiades were a group of happy children skipping off into the sky and having such a good time that they never came back. The Greek legend makes them the daughters of Atlas, all very beautiful. Jupiter assumed the disguise of a bull, Taurus, in order to carry away Europa, whom he considered the most beautiful, from her sisters when they were playing in the meadows.

Alcyone or Halcyone is the brightest star of the group. It used to be thought that the kingfisher, Halcyone, nested about the time this star culminated at the time of the winter solstice. Ceyx, king of Thessaly and husband of Halycone, was drowned. She, seeing his body floating, repeatedly rushed into the sea to save him. Then the gods changed them both to halcyon birds, and they go skimming across the waters and rushing into it always.

The Pleiades lie on the neck of Taurus, the Bull (Fig. 17, p. 32). The head of the animal is indicated by a V-shaped figure to the southeast of the Pleiades. One star of this group, Aldebaran, is a first-magnitude star and is one eye of the Bull. The V-shaped group forming the tips of horns, eyes, and the tip of the nose is known as the Hyades. The Roman year began in March when Taurus was just visible above the eastern horizon. Hence Virgil's line: "The white bull opens with his golden horns the year." Only the head and shoulders of the Bull are pictured as visible in the old star maps, for his body is supposed to be submerged in the sea, in which he is swimming to make his escape with Europa after capturing her in the meadows near the shore.

A line run through the Pleiades and Aldebaran and still farther to the south and east reaches three bright stars in line, the belt of Orion, the Hunter. This constellation of Orion is the most brilliant in the sky. To the south of the belt is a first-magnitude star, Rigel, and to the north one that has a reddish

cast, Betelgeuse. Two other stars about as bright as those of the belt lie, one near Betelgeuse, and one near Rigel. There are also several fainter stars in the figure, three of which in line near the belt make a portion of the Hunter's dagger. The middle one of this trio is imbedded in nebulous matter, the great nebula of

FIG. 17.—Taurus, the Bull

Orion. Orion, the Hunter, stands with club upraised about to strike Taurus in an attempt to rescue Europa (Fig. 18).

Orion's father, according to another Greek legend, was an old man and childless, a hunter by trade. One day three strangers came to his hut, whom he entertained right royally. On leaving they asked him what thing he most wanted. He replied "a son." Jove, who was one of the strangers, granted his wish,

and when the boy was born he was named Orion. When grown he became a mighty hunter, so tall he could wade the sea. He found some beautiful girls playing ball one time, and ran after

FIG. 18.—Orion and his dogs, Canis Major and Canis Minor

them. The girls, exhausted, were changed to birds by the gods and later into stars, the Pleiades. Later he met Diana, the hunting goddess, and fell in love with her. Her brother Apollo, fearing she would consent to marry him, seeing Orion approach over the ocean, merely a black speck in the distance, challenged

Diana to try her skill with her arrow and see if she could hit the tiny thing. This she did, and when she found out that she had killed Orion she was so much grieved that she gave him immortality among the stars and made him outshine all his rivals.

To the east of Orion (below in the winter evenings) is the most brilliant star in the sky, Sirius, in the constellation of

FIG. 19.—Gemini, the Twins

the Great Dog, Canis Major. Sirius, Betelgeuse, and Procyon, a first-magnitude star in the Lesser Dog, form an isosceles triangle, Procyon forming the northern apex. The Great and Lesser Dogs are following the Hunter, Orion.

Another larger triangle with Sirius and Aldebaran at the basal corners has a bright star, Pollux, one of a pair, at its northern

apex. The other star is Castor, and the two mark the constellation of Gemini, the Twins (Fig. 19). Another pair, similarly spaced but farther south, are also in this constellation of Gemini. Castor and Pollux were the sons of Leda, and Helen of Trojan fame was their sister. "They accompanied the Argonautic expedition, and, when on the return voyage the vessel was almost overwhelmed in the storm, Orpheus with his lyre invoked Apollo, who caused the two stars to appear on the heads of the twins and so the tempest was allayed." So these stars became the protective portents of sea-going men as the gods Castor and Pollux were the tutelary gods of sailors. Altars were erected to them in all important seaports, and often a vessel carried as a figurehead on her prow the symbol of Castor and Pollux, as did the ship in which Paul sailed for Rome. St. Helen's fire or St. Elmo's, a single flame on the mast head or spar, is an evil sign, but twin flames are the sign of the presence of these gods and are propitious. "By Gemini" was a favorite oath among seafaring folk, and it still persists, modified to "by Jiminy."

Both Taurus and Gemini are among those constellations known as the zodiacal constellations, which were exceedingly important to the old astrologers in forecasting the future. The zodiac is a girdle of constellations stretching around the celestial sphere, among which the sun and the planets when seen from the earth seem to wander. These constellations named in order in a bit of doggerel are as follows:

> The Ram, the Bull, the Heavenly Twins,
> And next the Crab the Lion shines,
> The Virgin and the Scales,
> The Scorpion, Archer, and the Goat,
> Water-Bearer and Fish with tails.

Draw a line from Aldebaran through the Pleiades, and extend it beyond them half as far again as Aldebaran is distant from them, and it leads to two third-magnitude stars near which, toward the Pole, are three third-magnitude stars

forming a triangle (Triangulum). The former two are in Aries, a constellation in which alpha is a conspicuously bright star (Fig. 20).

Cancer, the Crab, is made up of inconspicuous stars, but Leo, the Lion, is easily recognized. When Castor and Pollux are on the meridian about the middle of March, there is a sickle-shaped group of stars to the east of them and about a third of the way to the horizon that marks the Lion. Regulus, the brightest star

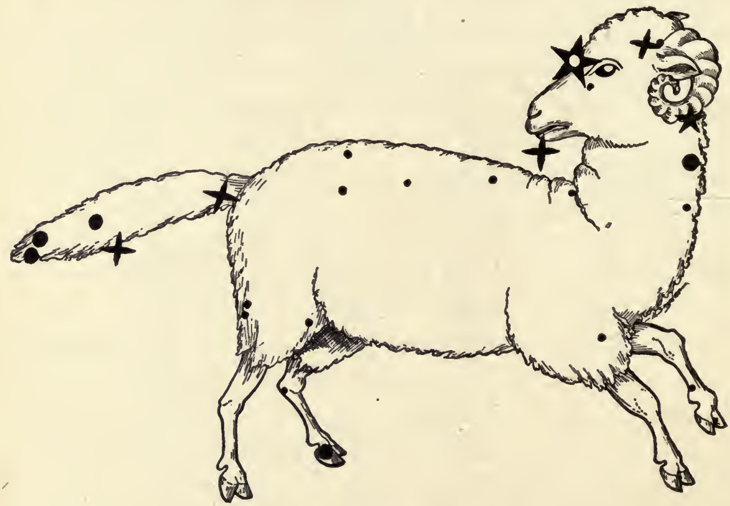


FIG. 20.—Aries, the Ram

of the constellation, is at the end of the handle of the sickle. Castor, Sirius, and Regulus make a triangle-shaped figure (see Fig. 21) that is the counterpart of the triangle formed by Castor, Sirius, and Aldebaran. Regulus is also at one corner of a nearby isosceles triangle with one of the pointers of the Dipper and Denebola, another bright star of Leo, at the other corners. Leo represents the Nemean lion, the fight with which formed the first of the celestial labors of Hercules (Fig. 22).

Still later in the spring, about 8:30 P.M. in the last of April, when the pointers of the Dipper are on the meridian, the next

FIG. 21.—Diagram to show the method of finding some zodiacal constellations and their relation to Ursa Major. Face north and hold it above your head.

FIG. 22.—Leo, the Lion

zodiacal constellation, the Virgin (Fig. 23), is readily located by its first-magnitude star Spica. This star, Denebola, and Arcturus form an equilateral triangle. Arcturus we have learned to find by extending the handle of the Dipper.

FIG. 23.—Virgo, the Virgin

Libra, the Scales, is a group of low-magnitude stars that originally formed a part of the Scorpion, the next constellation in the zodiac that is marked by a first-magnitude star, Antares. It is still low down in the southeast at 9:00 P.M. the last of May. A line drawn through the pointer in the Dipper that is farthest from the Pole and the star in the outer end of the handle leads

across the sky to Antares. It has a third-magnitude star close on either side of it; a line drawn through these leads to two second-magnitude stars, one on either side, that are about as far from Antares as the length of the Dipper handle. These also are in the Scorpion.

Vega in Lyra is about on the meridian at 10:00 P.M. the first of August. A line drawn through the polestar and Vega and continued nearly to the southern horizon leads to an irregular group of third-magnitude stars, conspicuous only because there are nine of them in a nearly horizontal group. These are in Sagittarius, the Archer. The Goat and the Water-Bearer are not marked by any conspicuous stars.

In the evenings of mid-September, when the square of Pegasus is a conspicuous object in the sky, to the east of the meridian there is an irregular V of dim stars on the side of Andromeda away from the Pole. The point of the V is well down, then, toward the horizon, the arms rising so as almost to inclose one end of the square. This line is the constellation of the Fishes, two of them caught on the ends of one line.

As suggested above, these zodiacal constellations were considered of great importance by the old astrologers. At the exact time of a person's birth the heavens were divided by these sages into twelve houses by great circles passing through the zenith and nadir of the place of his birth. These houses beginning in the east and passing around to the north, then west, were: (1) life and health; (2) riches; (3) kindred; (4) inheritances; (5) children; (6) sickness; (7) marriage; (8) death; (9) journeys; (10) honor; (11) friends; (12) enemies. The position of the planets and of the twelve signs of the zodiac in these houses determined the forecast of the person's nativity. Certain planets were fortunate, such as Jupiter, the sun, Venus, Mercury. The others, Saturn, Mars, the moon, were unfortunate. Thus Jupiter in the first house at one's birth meant long life and excellent health. Each zodiacal sign was connected with certain personal characteristics. Our language bears evidence still of

the prevalence of such early notions. One is capricious if Capricornus was in the ascendant house at birth, saturnian when the baneful influence of this planet was potent at his birth. The whole process of forecasting one's nativity or of predicting what might be expected on a particular voyage or in special circumstances was a complicated one; enough has been suggested to give some simple notions of the basis on which the astrologer proceeded. The books of the astrologers make strange reading now.

There is one other procession of constellations that passes in review in the southern skies that is exceedingly interesting, because it seems to be a memorial of a great disaster, the flood, the legend of which has come down to us in many literatures also.

At 6:00 P.M. in the middle of January there is a brilliant first-magnitude star in the southwestern horizon, Formalhaut, in the constellation of the Southern Fish. A line drawn down through the two westernmost stars of the square of Pegasus leads a little to the west of this star. West of this line and not quite halfway from the square to Formalhaut is a line of three close-set, third-magnitude stars that mark Aquarius, the Water-Bearer. The ancient figures show Aquarius pouring a flood out into the mouth of the great fish. In the same region are the Whale, the Dolphin, and the other fish, already located. In the eastern sky is to be seen the river Eridanus. It is an irregular line of stars ending near Rigel and including all the plainly visible stars in the southeastern sky at this time.

When Sirius is nearing the western horizon in the evenings of spring, say at 8:00 in the middle of April, there lies close to the horizon, stretching from a point south of Canis Major over past the meridian, a string of dim stars with a few of the third magnitude that mark the figure of a ship or ark, if much imagination is used, the constellation Argo Navis.

In the southeastern sky, symmetrically placed with respect to the meridian with Sirius is a close crescentic group of five stars,

two quite bright, the constellation of the Raven, Corvus. Streaming back from Corvus over toward Procyon is a line of dim stars

FIG. 24.—A group of southern constellations

forming the monster, Hydra, on the back of which the Raven is supposed to stand.

When Corvus is on the meridian about 9:00 P.M. on May 10 or thereabouts, the southeastern sky displays a cluster of five third-magnitude stars and farther east two of second magnitude, all in the constellation of the Centaur. When Arcturus is on the meridian not far from the zenith at 9:00 P.M. in the middle of June, the two bright stars in the Centaur (second magnitude) are one on either side of the meridian close to the southern horizon. This figure, designated the Centaur with his bow and arrow in hand in the Greek star lore, was represented in the earlier astrological charts as Noah placing a sacrifice on the altar, while overhead stretched the bow of promise.

This whole series of constellations, the flood poured out by the gigantic Water-Bearer, the numerous sea beasts, the mighty river, the Ark, the Raven that was released to find dry land, and finally the commanding figure of Noah, sacrificing on his altar with the rainbow near at hand—all these emblazon on the southern sky the interesting flood legend that runs continuously during the evenings from January to midsummer.

CHAPTER II

THE EARTH'S ROCK FOUNDATIONS

Sermons in stones and good in everything.—SHAKESPEARE, *As You Like It.*

Has it ever been your good fortune to be possessed with a mania for collecting? It matters little what the material is, whether butterflies, beetles, stamps, coins, shells, or minerals, the young collector generates a degree of enthusiasm for his pet hobby that stimulates endeavor, carries him through volumes of learned scientific discussion, sends him to geographies, encyclopedias, and histories for concentrated study that no school course arouses, makes him a purposeful correspondent, and frequently leads him to books on travel, or the biographies of great explorers with an appreciative fellow-feeling that leaves an indelible imprint on impressionable youth. The writer recalls to this day the delights of a boyhood spent among the rocky hills of northern Michigan. It is a mining region whence came great quantities of the world's best iron and copper, with some silver, gold, and other mineral products. Many a Saturday or holiday was occupied in wandering with hammer and specimen bag over the rock dumps at the mine, or in rambling over the hills in search of new finds. And what thrills came when some new specimen was found to add to the cabinet! Of course there were chums who were also enthusiasts. I recall how Charlie and I had for months cast longing eyes on a "vug" or pocket in a great quartz vein that went zigzagging down the face of a rock wall in one of the open-pit mines. We knew that such a place was likely to yield some fine quartz crystals. But it was 50 feet down the precipitous side to the pocket, and another sheer drop of as much more to the bottom. Finally, one

Saturday we ventured. Twisted strands of clothesline, purloined for the occasion from our respective back yards, were fastened securely to the root of an old but sturdy stump above the vug, and by its aid we scrambled down. The wall curved at the spot we wanted to reach, however, and we were forced to swing in, dangling on the rope, until our feet caught a rocky shelf just below the pocket. Precariously perched there, we dug out handfuls of soft, slimy hematite, bushels of it, it seems to me as I recall it now, until at last we began to feel in the lumps the loose crystals. These went into the collecting bag until it was well loaded. When the vug was emptied of all its treasure, the bag was lowered to the bottom of the pit. We slid and climbed down, then made our way with our load up the steep surface of a pile of waste rock with which the abandoned old mine was being filled. I still have the most perfect of these clear crystals and cannot bear to part with it for recollection's sake.

It is a splendid thing if some one of these enthusiasms of boyhood days carries over into adult life, an avocation to relieve the strain of the serious life-vocation, if it does not lead, with added years, to the vocation itself. A great lawyer of national reputation is known in scientific circles as an enthusiastic collector and an authority on snails of the Middle West. A physician of my acquaintance follows as his hobby, still, a boyhood delight in collecting wasps, and is a recognized specialist in this group. A business man has camped during his vacations these many years on the famous fossil-collecting grounds of many states, adding each time to his splendid collection.

If the work in elementary science could impart to every boy and girl a sufficient interest in minerals and rocks so that they would, for a while at least, collect with enthusiasm, it would be eminently worth while; for the pupils might get, then, some glimpse of the wonderful history of our earth and the marvelous processes that have been at work to make the rock-ribbed hills, some appreciation of the striking series of episodes in the history of even the commonest pebble.

Dig down into the soil anywhere and you finally come to the solid rock on which the soil always rests (Fig. 25, p. 46). Sometimes the soil is only a thin cover for the rock that lies close to the surface; again it may be a thick blanket. In the hill or mountain regions the bare rock may cover miles of area with scarcely a vestige of soil upon it. Bore down into the rock as deeply as man has been able, or sink a mine shaft, and the going is all the way through solid rock. True, our deepest mines and borings explore only the outer part of the earth, penetrating but a little over a mile. The J. H. Lake well at Fairmont, West Virginia, is 7,579 feet deep. But they tell us that this outer portion is all made of just such rock as we find somewhere at the surface. Such rock may be a great mass of a single mineral or it may be composed of grains or crystals of minerals all firmly pressed together.

By a mineral we mean any inorganic substance composed throughout of one definite or nearly definite chemical substance. Limestone, the common bed rock of the Chicago area, is a rock, and the mineral of which it is made is called calcite, which is chemically a carbonate of lime. Sandstone, another widespread rock, is made of grains of the mineral quartz, cemented together with more or less lime. Granite, on the other hand, is made up of bits of several minerals, quartz and feldspar certainly, and frequently others as well, all making the solid rock.

Most minerals occur as solids, though a few are liquids in a state of nature. Thus mercury may occur in drops, sulphur in pools or even lakes of the molten mineral. If the term, mineral, as defined is taken in its broadest sense it will include certain gases like nitrogen, oxygen, and steam, but here it is used with its more customary meaning.

A few minerals are chemical elements; that is, they cannot by ordinary means be broken up into simpler things. Such, for instance, are certain metals like iron, copper, gold, silver. These occur in the rocks at times in grains or even in good-sized chunks of pure or native metal. Masses of such native copper were highly

Fig. 25.—Soil underlain by rock

prized by the Indians and Eskimos, for from such they laboriously cut off bits that could be hammered into arrow- and spearheads or even shaped to make crude knives. The copper ore of the famous Calumet and Hecla mine in upper Michigan is a rock in which the native copper occurs in grains or threads. Gold ordinarily occurs as grains, flakes, or strings in the quartz veins, from which it is separated by crushing and washing.

Some of the non-metals occur similarly in the free state as elements. Sulphur is a good example. In volcanic regions, especially, great deposits of it are found. In some of the coastal regions bordering the Gulf of Mexico it is very abundant as grains or small masses in the deeper layers of the sand. Live steam is forced down to melt it, and the melted sulphur comes to the surface through pipes sunk for the purpose. Until these deposits were discovered and a method of working them perfected, the United States imported its sulphur largely from Italy and Sicily. Now we export sulphur in quantity.

But for the most part the minerals are compounds; that is, they consist of two or more elements united in a chemical compound. Thus, while silicon is, next to oxygen, the most abundant element in the earth's crust (making, it is estimated, one-fourth of it), yet the element occurs nowhere in the earth free, but it is united with other elements. Combined with oxygen it makes silica or quartz, SiO_2, one of the most widely distributed of minerals. It is found as an element in many of the other common minerals which are complex silicates, as will be seen below. Calcite, the mineral from which vast deposits of limestone and marble are formed, is a compound of calcium, carbon, and oxygen, $CaCO_3$.

While the mineralogist knows hundreds of minerals, most of them are rare, and, fortunately for the beginning student, those that occur as essential constituents of the common rocks are not many, and they are, moreover, distinguished with comparative ease. Before describing these it will be necessary to review some of the important characters that serve as distinguishing features

and to understand some descriptive terms. It would be well for the reader to obtain from some dealer in minerals and rocks a collection of those described in the following pages in order that he may have in hand a specimen to observe as he reads the description.

In solid form, minerals may be crystalline or non-crystalline. In the latter case they are described as amorphous, the terms amorphous and non-crystalline being synonymous. The forms of the crystals of any specific mineral are always constant. Thus

FIG. 26.—Crystals

quartz crystals are always six-sided prisms with a six-sided pyramid on each end if the crystal is perfect. Hematite crystallizes in cubes, pyrite in cubes, octohedra, or duodecahedra. The very definite form of the crystals, if the mineral is crystalline, is one means of distinguishing it (Fig. 26).

Many minerals break along definite planes so that the fragments are bounded by smooth surfaces that meet always at the same angle. This property is called *cleavage*. Thus galena always cleaves into cubes, calcite and feldspar into rhombs, though the angle between the faces of the rhombs are different in the two cases. Mica cleaves into thin plates and asbestos

into needles or threads. Cleavage, then, is another physical feature that aids in the determination of minerals (Fig. 27).

Certain minerals break in a characteristic way other than along cleavage planes. The mineral is then said to possess a peculiar *fracture*. Thus flint breaks with a conchoidal fracture, the surface of the break being either concave or convex like a clam shell.

FIG. 27.—Feldspar, to show cleavage

The fresh surface of many minerals so reflects the light as to give it a peculiar *luster*. Thus quartz usually has a vitreous or glassy luster, galena a metallic luster, selenite a pearly luster, chalcedony a waxy luster.

Then many minerals when scratched or, better still, when rubbed on a piece of unglazed white porcelain yield a *streak* that is peculiar. In this manner hematite is distinguished from limonite, which it often resembles, for the former yields a red streak, the latter a yellowish-brown one.

Finally, the *hardness* of the mineral is an important aid in its determination. So important is this that a very definite scale of hardness has been arranged, running from the very soft minerals with a hardness of "one" to the diamond with a hardness of "ten." This scale is as follows: talc with a hardness of 1; gypsum, 2; calcite, 3; fluorite, 4; apatite, 5; orthoclase feldspar, 6; quartz, 7; topaz, 8; corundum, 9; diamond, 10.

Minerals may be classed from the point of view of rock formation into essential and accessory. Quartz and orthoclase feldspar are essential ingredients of granite. A rock would not be named a granite unless composed largely of these two minerals. Other minerals, such as mica, hornblende, etc., may be present in relatively small quantity and the rock still be a granite. Such are the accessory minerals. Essential minerals are those the presence of which determines the name of the rock. Accessory minerals are those that may be present but need not be so necessarily. The chief minerals that play essential rôles are quartz, calcite, the feldspars, mica, amphibole, pyroxene, dolomite, serpentine, kaolin. These are not always essential; they may at times be accessory. The accessory minerals are much more numerous. Only a few of the more important can be mentioned, such as magnetite, hematite, limonite, pyrite, chlorite, olivine.

Then there is a large group of minerals which are important primarily as ores of the metals used so largely in industry. Some of these, as already indicated, are accessory ingredients of rocks. There are magnetite, hematite, limonite, oxides of iron; pyrite, a sulphide of iron; siderite, a carbonate of iron; chalcopyrite and bornite, copper iron sulphides; azurite and malachite, copper carbonates; galena, lead sulphide; sphalerite or "blackjack," a sulphide of zinc; cassiterite, an oxide of tin; cinnabar, mercury sulphide; pyrolusite, an oxide of manganese (Fig. 28).

Many other minerals are commercially valuable as sources of chemicals needed in industry. Such are halite or rock salt; borax, a borate of sodium; saltpeter, a nitrate of potash; soda

niter, a nitrate of soda; gypsum used as a fertilizer and in making plaster of Paris; sulphur; and corundum, which is so hard it is used in making grinding disks.

Mention should be made also of the very beautiful and rare minerals that are used as gems. The diamond is crystallized carbon. The sapphire and ruby are pellucid varieties of corundum. Emerald and aquamarine are lustrous forms of beryl, a silicate of berylum and aluminium. Topaz is a fluosilicate of

Fig. 28.—A zinc mine

aluminium. Garnet is also a silicate and the different varieties vary in the metals present: lime, aluminium, iron, soda, chromium, etc. Turquoise is a phosphate of aluminium.

Of all the minerals quartz is the most abundant in the rocks at the earth's surface. Sand consists largely of grains of quartz more or less rounded by water action. Sandstone, which is the prevalent surface rock over wide areas and is extensively used as a building stone, is simply sand cemented together to form rock, and so is quartz in great measure. Quartzite is another common rock made of quartz. It is really sandstone modified

by heat and pressure so that the individual quartz grains are fused together. Quartz veins occur in many rocks. When the rock cracks under the terrific strains of crust movements, wide fissures open that run for many miles in length and extend deep into the earth. Such fissures are often later filled with quartz deposited from water. Such seams of quartz are known as veins. Then again quartz is a very common constituent of many rocks like granite, diorite, etc.

Pure quartz in the amorphous or uncrystallized state is a milky-white rock that is so hard it cannot be scratched with a knife blade. When you attempt to scratch it, the steel rubs off on to the quartz, leaving a metallic streak. Quartz scratches glass easily. Quartz breaks with a conchoidal fracture, and the freshly broken surface has a glassy sheen, or, as the mineralogist says, a vitreous luster. Quartz is so hard it is little subject to the wear and tear of the elements. Heat and cold, rain and frost, have little effect upon it, so that quartz veins usually stand out of the rock in which they occur since the rock containing them is likely to weather more readily than the quartz. Quartzite hills are likely to be rugged for the same reason, the contours being angular, the slopes precipitous.

Ultimately, of course, even resistent quartz is broken up under the incessant attacks of the elements. It will crack as it is alternately heated intensely by the mid-day sun and suddenly cooled by the rain or the low temperature of night. Water accumulating in the tiny cracks changes to ice in winter and in changing expands, heaving the quartz apart and widening the crevices. Thus even quartz breaks in time into angular fragments. The pelting rain, acting through countless centuries, will wear away the angular edges, rounding off the fragments. The smaller pieces may be washed down the slopes into the streams, rolled along by the spring freshets, and ground against each other until they are worn down to rounded pebbles. In time they may be carried to the lake or sea and further pulverized by wave action until the quartz block is transformed into sand.

So, too, when such a rock as granite disintegrates under constant weathering, the angular quartz grains wear down much less readily than the other minerals. But still in time they are rounded by water action and reduced to sand. Sand, the grains of which are still angular and sharp edged, is called torpedo sand.

Pure quartz, when crystallized, forms transparent crystals in the form of six-sided prisms with a six-sided pyramid on each end. Such crystals, because quartz is so nearly indestructible, are much used for spectacle lenses and for lenses in optical instruments such as microscopes. The crystals are very likely in nature to form on a surface, the prisms standing up on end capped with a pyramid at the free end but lacking the pyramid at the base (Fig. 26, p. 48, right end).

While quartz does not dissolve readily in ordinary water, it does dissolve with comparative ease in water that is charged with carbon dioxide, especially if the water is hot and under pressure. Now carbon dioxide results from the decomposition of organic material. Soils usually contain a great deal of it, especially in marshes and forests where much decaying plant and animal material lies on or in the ground. Rain falling on the ground percolates through it and absorbs much carbon dioxide as it goes. If this water then finds its way down into the rock layers, running through their cracks and crevices, and so sinks into the rock of the earth's crust, it may become hot. As it heats it expands and in the confined spaces may develop a high pressure. Then it dissolves quartz readily. Later it may be forced to the surface again, appearing as a hot spring. About the mouths of such hot springs quartz is deposited abundantly, for as the water comes to the surface it is free to expand, the pressure decreases, the water cools and loses its carbon dioxide to the air, and so it can no longer hold the quartz in solution.

Not infrequently such alterations in temperature, pressure, and carbon dioxide content occur in part as the water flows into a cavity in the rock, and then the cavity is lined with layer after

layer of quartz, the innermost layer often being a layer of upstanding crystals. Later on, the rock containing such a hollow mass of quartz may disintegrate, freeing the quartz mass. Such a rounded chunk with a hollow center lined with crystals is known as a geode.

The layers of quartz deposited in a rock cavity or at the surface about a hot spring may have a waxy luster. Such quartz is known as chalcedony.

But the quartz in the process of solution in water and redeposit is very prone to become impregnated with impurities that color it. So quartz either in the massive or crystalline condition may assume almost any color. A very beautiful variety of massive quartz is tinged with pink and is known as rose quartz. Quartz crystals may be tinged with purple and are then called amethysts. They are so beautiful as to be in demand for gems. So the crystals when tinged with yellow are mounted as topaz, although they are false topaz, as the real gem is still harder and more lustrous than quartz. Similarly, red quartz crystals make false rubies; green, false sapphires. The crystals may be hazy with dark coloring and are then known as smoky quartz.

The layers of quartz deposited in cavities or about the mouths of hot springs may be colored with different tints as first one impurity, then another, is predominant. If the layers are varying shades of red, onyx is produced. Rounded masses of quartz deposited in varicolored layers in some small cavity of the rock and later set free by rock disintegration are known as agates. The layers may be shades of red, varying degrees of dark colors, blues, or yellows. Such an agate may look like an ordinary rounded quartz pebble or bowlder when found, for the exterior is rough and water-worn, but when broken open it displays the concentric colored layers. When ground down and well polished it is a thing of marvelous beauty. Some very exquisite vases and bowls are made of agate, chalcedony, and onyx, and the latter is used for table tops or even decorative pillars in the interiors of costly buildings.

The most beautiful gem in the quartz group is opal. This is a form of quartz found usually in volcanic rocks. It has a texture that makes its luster exceptional, so that the stone gives off reflections of brilliant color that change according to the angle at which it is viewed, now red, now green, blue, yellow. The most brilliant opals are those that dart shades of red like flames, and such are known as fire opals.

Next to quartz the commonest rock-forming mineral at the earth's surface is calcite. This is a carbonate of calcium ($CaCO_3$). It crystallizes in a variety of forms of which the rhombohedron is the most common. It then easily cleaves along the planes of the crystal faces in three directions, so that the pieces are bounded by plane faces like a cube, but unlike a cube the angles at which the faces meet are not right angles but are about 78° and 102°. The opposite faces are parallel to each other and alike, though they are not squares, as in the cube, but quadrilaterals whose sides meet at the same angles as the faces. These angles between the faces are always the same in the fragments, so the fragments are all rhombs.

Calcite may be quite transparent, when it is known as Iceland spar because such beautiful specimens of the mineral are to be found in that locality. This spar has a peculiar effect on light that passes through it, so that when a piece of the spar is placed on an object, such as a printed page, each letter appears double. The spar is said to be doubly refractive.

Calcite, when pure, is transparent, translucent, or white, but it may assume many different colors as it takes up various impurities. It may be red or yellow from the presence of iron oxide, or blue, green, and other tints from other substances. It is a soft mineral with a hardness of 3, and so is easily scratched with a knife. It decomposes readily in dilute acids, yielding an abundance of carbon dioxide gas, so that when a drop of such acid is placed on it, or a small fragment is put in acid, it effervesces, the gas bubbles coming up through the acid as they do in soda water. The softness, the rhombohedral cleavage, and

this effervescence with dilute acids make it easy to determine calcite. The only mineral with which it is likely to be confused is dolomite, a carbonate of magnesium that is heavier, harder, and effervesces in strong acids or in weak ones only when powdered.

Calcite is very prevalent, forming great beds of rock. Limestone, chalk, and marble are made of calcite. The calcite in limestone is usually in grains, while in chalk it is still finer—a dust. Marble is derived from limestone through alteration by heat and pressure, and is crystalline; the calcite in limestone and chalk is non-crystalline.

Calcite is a representative of several minerals that are also carbonates. The most important as a rock-forming mineral is dolomite, a carbonate of magnesium. Marble which contains much dolomite instead of calcite is known as dolomitic limestone.

There is one sulphate of calcium that is a frequent ingredient of rocks and that forms extensive beds in certain localities. This is gypsum. The very clear crystals of this mineral are known as selenite, while the pure white amorphous form is called alabaster.

The term feldspar is used to designate a group of minerals rather than one. They are of unlike chemical composition, though closely similar. In this respect, therefore, the term feldspar is not co-ordinate with quartz and calcite, for these terms indicate single substances of a definite chemical composition. The feldspars are, however, very similar in appearance and have like physical properties. They are all complex silicates of certain basic elements, sodium, calcium, potassium, and aluminium. Orthoclase is a silicate of potash and aluminium ($KAlSi_3O_8$); albite, similarly, a silicate of sodium and aluminium ($NaAlSi_3O_8$), while anorthite is a silicate of lime and aluminium ($CaAl_2Si_2O_8$).

These feldspars occur rarely in rocks as such, but freely as mixtures, two of them being usually fused together. Orthoclase and albite fuse in making a series of potassium-sodium-aluminium silicates. If the orthoclase feldspar is largely dominant in the

mixture, as is usually the case, the fused product has the properties of this mineral and is still known as an orthoclase feldspar or potash feldspar. The mixtures of anorthite and albite are known as plagioclases or soda-lime feldspars. A distinctive name has been given to that feldspar that is a product of the fusion of anorthite and albite in about equal amounts. It is called labradorite.

All the feldspars cleave readily in two directions, and the cleavage faces are at right angles to each other (in the orthoclases) or at slightly oblique angles in the plagioclases. The cleavage faces of the plagioclases are striated with many fine parallel lines. In directions other than along the cleavage planes feldspar breaks with an uneven fracture. Even in small fragments found in such rocks as fine-grained granite it is usually possible to see the cleavage faces with the hand lens sufficiently distinctly to recognize the mineral.

Pure feldspars are colorless, but they are seldom pure. Orthoclase is usually tinged with red, varying from pale pink to deep brick red; the color seems due to the presence of fine particles of iron oxide scattered throughout the mineral. Plagioclase is commonly gray, while labradorite is likely to be dark, smoky gray, or even black. The colors are not dependable as absolutely reliable distinguishing features, however, since plagioclase is sometimes red, and orthoclase may be gray or dark. The ready cleavage in two directions at right angles or nearly right angles to each other, the vitreous luster on fresh fractures in other planes, and the hardness are the chief features to be relied upon in field determination. The feldspars have a hardness of 6, scratching glass, but being in turn scratched by quartz. The feldspars are probably the most widely distributed of rock-forming minerals, though not occurring in such large quantities as those previously mentioned.

Chemically, the feldspars are representative of a large majority of the minerals which, like them, are complex compounds of various basic elements with some one of the series of silicic acids.

All such are primary minerals; that is, they are formed directly in the cooling of molten materials. Such primary minerals contain no water. In addition there is a series of minerals, also silicates, that contain water. The former are the anhydrous minerals, the later the hydrous. These secondary minerals are the result of alterations of the primary ones through the addition of water and other chemical changes. Among the important primary anhydrous silicates are the pyroxenes, the amphiboles, olivine. The hydrous silicates include mica, kaolin, the chlorites, serpentine, talc.

The pyroxene group includes hypersthene, diopside, common pyroxene, augite, and aegirite, all similar in physical properties but differing in the relative amounts of magnesium, iron, calcium, sodium, and aluminium that combine with the silicic acids to form the mineral. Pyroxene and augite are the commonest and may be taken as typical. Both consist of silicates of calcium, magnesium and iron, the latter containing aluminium also. The pyroxenes are dark green in color, the augite, black. They are quite hard, 5–6. The fracture is uneven, but they cleave fairly well in two planes that are so nearly at right angles to each other that they appear such except on very careful measurements. They crystallize usually in short, thick crystals that are eight-sided prisms, the ends capped with four-sided pyramids, which, however, are commonly very imperfect, frequently reduced to two faces.

The amphiboles or hornblendes include also a series of minerals which are so much alike that for our purposes we may describe common hornblende as typical. If the beginner can distinguish it in the rocks it will be sufficient. Hornblende looks on casual inspection much like pyroxene. It is green to black, has a hardness of 5–6, and occurs in the same dark igneous or metamorphic rocks. However, it has a highly perfect cleavage in two directions, the cleavage planes meeting at angles of 55° or 125°; pyroxene, it will be recalled, cleaves at right angles and not very perfectly. The crystals are long and slender, as a rule,

and are six-sided in cross-section, the faces meeting at angles like those made by the cleavage faces. The luster on freshly broken surfaces is bright and vitreous, while in pyroxene it is commonly dull. Hornblende occurs sometimes in a finely columnar or even fibrous form known as asbestos; then the luster is silky.

Olivine is an olive-green to bottle-green mineral, harder than pyroxene or hornblende (6.5–7). It is transparent to translucent. It cleaves only in one direction. It occurs in the igneous rocks in grains, and might be mistaken for the preceding minerals at first sight, but its greater hardness and cleavage in only one direction will distinguish it.

The micas are readily distinguished because they cleave so readily into very thin *elastic* plates. The commonest ones in rocks are muscovite, a light-colored one, which is a hydrated silicate of potassium and aluminium; and biotite, dark brown to black, a hydrated silicate of iron, magnesium, and aluminium.

Kaolin, which is a very pure clay, results from the disintegration of the feldspars or similar minerals in the presence of water and carbon dioxide. It is a silicate of aluminium combined with water ($H_4Al_2Si_2O_9$). It usually occurs in great masses or beds, is soft, white, and has a greasy feel when rubbed between the fingers. It is readily tinged with impurities, becoming yellow, brown, or gray. It also occurs in beds more or less mixed with other substances—sand, mica, hematite, organic matter, etc.—and so gives the ordinary clays. Such beds are important in rock formation, for out of them have been made some important sedimentary and metamorphic rocks.

Chlorite is another hydrous silicate resulting from the weathering of the anhydrous sorts. In reality there are several chlorites, but all are much alike and may be treated here under the one heading. The color is green; the cleavage is much like that of mica, but the flakes, while bending easily, are inelastic and remain bent instead of springing back to their original form as do the micas. Chlorite is so soft, too, that it is scratched by the finger

nail. Chlorite gives its green tinge to many igneous rocks known commonly as green stones, and to some schists and slates.

Serpentine is usually massive, sometimes fibrous like asbestos (chrysolite). It is green in color, occasionally so dark as to be nearly black. It has a greasy feel, a waxy luster (pearly in the fibrous sorts), and is quite soft (2.5–3). It is not only a common accessory mineral in many igneous and metamorphic rocks but also forms great bodies of rock itself.

Talc is readily recognized by its softness. It makes a light streak even on cloth. It is usually white to green. It is somewhat laminated like mica, but the flakes are inelastic. It has a distinctly greasy feel.

Such, then, are the common rock-forming minerals. The student should be familiar with them before he goes on to a study of the rocks. The following tabulation will serve to give the characteristics in condensed form.

KEY TO COMMON ROCK-FORMING MINERALS

So soft they can be scratched with the finger nail	Chalk, 0.5–2.5	White to gray, dull, crumbles in fingers, no earthy odor when breathed upon, effervesces with acid.
	Chlorite, 1.5–4.0	A green mineral of pearly to vitreous luster with greasy feeling. It usually occurs in grains or scales in basic rocks.
	Gypsum, 1.5–2.0	Many colors, streak always white. Massive (alabastine), fibrous (satin spar), foliated (if transparent called selenite).
	Kaolin, 0.5–2.5	Many colors, streak like color. Feels greasy. Strong clay odor when breathed on. Dull to pearly luster; brittle.
	Mica, 2.2–5.0	Perfect cleavage; very thin elastic scales can be obtained. The black sort is biotite; the colorless, gray, or pale green, muscovite.

KEY TO COMMON ROCK-FORMING MINERALS—*Continued*

Easily scratched with a knife	Galena, 2.5	Lead gray, streak same. Metallic luster. Very heavy; cleaves in cubes.
	Serpentine, 2.5–4.0	Color, shades of green. Luster greasy, waxy, or earthy. Feels smooth or greasy. Compact and amorphous, making a rock of the same name.
	Calcite, 3	Many colors, streak white to gray. Always cleaves into rhombs. Effervesces in dilute acid.
Scratched with a knife with difficulty	Sphalerite, 3.5–4.0 (Zinc blende)	Yellow, red, brown, black. Luster resinous when yellow. Perfect cleavage. Brittle.
	Chalcopyrite, 3.5–4.0 (Copper pyrite)	Brass yellow, often tarnished, then showing iridescence. Streak green-black. Softer than pyrite.
	Dolomite, 3.5–4.0 (Pearl spar)	White, gray, green, black. Streak white. Transparent to translucent. Crystals curved like saddles.
	Mica, see above	
	Limonite, 5.0–5.5	Dark brown, streak yellowish brown. Often fibrous; if earthy, color is yellow. In cubical crystals.
Scratched by quartz but not with a knife	Pyroxene or Augite, 5–6	Green to black. Fracture uneven to conchoidal. Usually in short, thick, eight-sided prisms. Cleavage poor; faces meet at 90°.
	Amphibole or Hornblendes, 5–6	Brown, green, or black, darker than augite. Fracture as above. Luster pearly on cleavage faces. Crystals long, slender, six-sided, faces finely cross-striate. Cleavage faces meet at 125°.
	Hematite, 5.5–6.5	Cherry red to iron black; streak red. Metallic luster, massive or fibrous or scaly.

KEY TO COMMON ROCK-FORMING MINERALS—*Continued*

	Feldspar,* 6.0–6.5	Many colors, streak white. Cleavage perfect, faces at nearly right angles. Light colored, orthoclase; darker, plagioclase.
	Pyrite, 6.0–6.5 (Fool's gold)	Brass yellow, tarnishes brown. Streak greenish black. Metallic luster. Crystals, cubes or dodecahedra. Harder than chalcopyrite.
As hard as quartz	Olivine, 6.5–7.0	Green, streak white. Transparent to translucent. Usually occurs in rounded grains.
	Quartz, 7	Color anything from black to white. Luster vitreous or waxy in chalcedony. Fracture conchoidal. Crystals six-sided prisms ending in pyramids; blue, amethyst, banded agate, onyx, jasper. In massive nodules occurs as flint.

* The term feldspar stands for a group of minerals. Orthoclase is a silicate of aluminium and potassium—a "potash-feldspar." Its cleavage angle is a right angle, or nearly so. It is usually light in color, white, gray, pink. It commonly occurs in rocks in which quartz is present fairly abundantly and seldom associates with the plagioclase group. This plagioclase group includes the soda-lime feldspars like oligoclase and labradorite. The plagioclases have an oblique cleavage angle, and certain cleavage faces are marked with numerous fine parallel lines. The plagioclases, especially the oligoclase and the labradorite, are strongly basic, seldom occur with quartz in any quantity, often are present with augite or hornblendes. They are usually dark colored, blues, grays, or dull reds.

Rocks are constantly forming nowadays. When from some great volcano there is an outflow of lava, and this molten material cools and solidifies, it forms rock (Fig. 29). Such rocks, formed from the cooling of a molten mass, are known as igneous rocks. The wear and tear of the waves, ocean currents, and other agents of erosion disintegrate rocks, and the débris is carried out to sea. Offshore this material is being deposited as great beds of sand and mud. As this process goes on through countless years the deposits thicken, and the lower strata, subject to the vast pressure

of the accumulating layers above and to the internal heat of the earth, are transformed to rock. Just as man takes clay and by pressure and heat transforms it into solid brick, so in nature the loose sands and clays are by similar processes transformed to rock. A bed of sand, for instance, will make sandstone. Such rocks, the constituent materials of which are deposited by water and solidified by heat and pressure, are known as sedimentary rocks.

FIG. 29.—Basalt

Such processes of rock formation and rock disintegration by weathering and the re-formation from the débris have been going on for a very long time on the earth. The very old rocks, however, are all igneous apparently. The earth was at one time much hotter than now, volcanic activity was more intense, lava outflows were very extensive, and the early crust was made of the rocks obtained by cooling of this molten material. These very old rocks have, in a large measure, been covered up by later outflows of lava and by sedimentary deposits on top of them.

Still there are regions in which the very old rocks are found at the surface, later sedimentary rocks having been washed off from them; or else they have been brought to the surface by the folding and crumpling of the earth's crust. In mountain regions where volcanic activity is present, igneous rocks are very plentiful.

When a great mass of molten material like a great lava outflow cools, the surface layers cool first, naturally. These surface layers are made up of the lighter materials which have come to the top while the mass was still molten. Moreover, such molten masses are full of gases that are escaping and bubbling up to the surface. The rock, therefore, that first forms on the top of such a lava mass is likely to be frothy, light in color, and light in weight. Deeper down in the cooling mass the rock formed is glassy in its texture. Still deeper down as cooling goes on much more slowly, the ingredients of the molten mass crystallize as they cool. When cooling goes on fairly rapidly, crystals that form are very small; but as cooling goes on more and more slowly the crystals tend to become larger and larger. It is very evident that igneous rocks will vary in their structure according to the rate at which the original molten mass cooled. We may have rocks of spongy character, like pumice, glassy rocks such as obsidian, or crystalline rocks, and these latter may be either fine-grained like basalt or coarse-grained like gabbro. The coarsely crystalline rocks of all groups are called plutonic, for they have been formed, as a rule, deep down in the throat of the volcano. The finely crystalline, glassy, porous rocks are called volcanic, for they have cooled upon the surface of the earth as lava outflows.

The various minerals that enter into the composition of the rocks do not crystallize out all at the same time. Some begin to form as crystals when the molten mass is still quite hot. Others wait until the material has cooled a great deal. The minerals that contain large proportions of the heavier metallic elements, such as iron and magnesium, crystallize early. Plagioclase

feldspars crystallize out before the orthoclase, and quartz seems to be one of the last to crystallize. Not infrequently one finds a rock composed of a finely crystalline ground-mass containing large and distinct crystals of some constituent mineral. Such rocks are designated porphyries. In the porous rocks the cavities formed by gas bubbles have in some cases later been filled with some mineral deposited usually by water percolating through the rock. Such rocks with more or less spherical masses of mineral deposited in the cavities are known as amygdaloids.

Not only do the igneous rocks differ in texture but they differ also in chemical composition according to the prevalence of the various minerals. As noted already, most of the important minerals entering into the formation of igneous rocks are silicates. When metals combine with silica some of them take up large quantities of silica, others relatively small quantities. This depends upon the valence of the metal. Thus iron has a valence of four, as does manganese; while sodium and potassium have a valence of only one; calcium a valence of two. This means that iron is capable of combining with four atoms of monovalent substances, like hydrogen, say, while sodium can only combine with one. When, therefore, such a metal is combining with silica to form a silicate, the element with the greater valence will take up much more of the silica. The silicates of such metals as sodium and potassium, as we have seen in the orthoclase feldspars, are likely to be light in color and light in weight as compared with the minerals that are silicates of the heavy metals like iron and manganese, such as pyroxene and hornblende. The rocks formed from the combination of such light-colored and lightweight minerals are also prone to contain a great deal of free silica in the form of quartz, whereas, for the reason just given, the silica is not likely to be free in rocks made of the darker and heavier metals.

On the basis of these two characters—the texture of the mineral and the prevalence of certain constituent minerals—we can classify the rocks. In the accompanying tabulation (p. 66), the

rocks are divided into certain groups according to the dominance of certain minerals. In the granite group at the left, the dominant minerals are quartz and orthoclase feldspar. As you read to the right in this table through the succeeding groups, the quartz becomes a less and less conspicuous element in the rocks. The feldspars decrease in amount and those present are of the plagio-

TABLE OF IGNEOUS ROCKS

Granite-Rhyolite Group	Syenite-Trachyte Group	Diorite-Andesite Group	Gabbro-Basalt Group	Peridote Group
Quartz and Orthoclase Dominant	Orthoclase Dominant: Quartz Absent or Present in Negligible Quantity	Plagioclase and Hornblende Dominant: the Latter Equaling or Exceeding the Feldspar in Amount	Feldspar (Labradorite) and Pyroxene Dominant: the Latter Equaling or Exceeding the Feldspar in Amount	Feldspar Absent or Nearly So. Hornblende, Pyroxene, Olivine, the Dominant Minerals
Rhyolite pumice (porous) Rhyolite obsidian (glassy)	Trachyte (included in the felsites)	Andesite (included in the felsites)	Basalt tuff Basalt breccia Basalt Dolerite	
Granite (crystalline) Other minerals may be present but not dominant giving biotite-granite, hornblende-granite, etc.	Syenite	Diorite	Diabase (Olivine diabase, olivine gabbro, green stone) Gabbro	Peridotite
Porphyritic granite		Diorite porphyry	Diabase porphyry	
Pegmatite granite				

clase varieties; finally the feldspars disappear entirely. While in the granite group we may have hornblende or pyroxene present in small quantities, in the right-hand groups these minerals come to be the dominant ones.

Reading down in any one of the groups, the texture of the rocks varies from a spongy texture, through a glassy texture to the crystalline texture, and the latter is first fine, then coarse. In some of the groups these spongy and glassy rocks are missing.

Thus in the granite group we have first pumice, then obsidian, then granite, and the granites may vary from very fine-grained to very coarse-grained granite, the latter being not infrequently porphyritic.

Rhyolite pumice is a spongy glass. It is light in color, porous, and, therefore, light in weight. It is found only in the regions where volcanic action has occurred comparatively recently. Rhyolite obsidian also occurs only in the regions of recent volcanic activity. It is a glassy rock which breaks with a conchoidal fracture. It varies greatly in color from a light to so dark a tint that it is almost black.

The granites consist essentially of quartz and orthoclase feldspar or at least of feldspars that have so large a mixture of the orthoclase as to have its characters predominant. The granites may be fine-grained or coarse-grained. If one constituent is very coarse-grained and the others more finely crystalline, the granite is spoken of as a porphyritic granite. A number of other minerals besides the two essential ones may be present; mica, especially the biotite form, is very often present, hornblende and pyroxene are frequent ingredients, but never dominant. If these darker minerals are present in quantity, the granite, of course, is very dark. Sometimes the quartz crystals are scattered through the granite in rather regular lines and are frequently twinned, making the rock appear like a slab of feldspar with more or less regular lines of angular quartz figures giving the appearance of Arabic writing; such granite is known as pegmatite.

Granites are very widely distributed especially in the regions where the older rocks are exposed; for a large proportion of these older rocks are of granitic character. They are found consequently as the core of mountain systems where the later sedimentary rocks have been worn away from the crest of up-arched strata. They occur abundantly in the Laurentian Highlands of Canada, throughout northern Michigan, Wisconsin, Minnesota, along the Appalachian Mountains, running through New

England, New York, the Virginias, and Carolinas, and down into Georgia. They are similarly found in the Rocky Mountain regions and in the Ozarks.

Because of their very wide distribution, the granites have played an important part as the source of soils. The feldspar which they contain weathers readily and, as a result of its weathering, changes to kaolin, which, when permeated with such impurities as the oxides of iron, gives our common clays. The quartz is, of course, more resistent to the weather but is sorted out by the water, is more or less weatherworn, and is deposited as beds of sand.

In the syenite-trachyte group only two rocks are given. The syenite is the coarsely crystalline or plutonic member; the trachyte, the finely crystalline or volcanic member. The syenites are not very common. They consist of orthoclase chiefly, though other minerals, like mica, hornblende, pyroxene, may be present. The quartz is either absent or present in such small quantities as to be a negligible constituent. Trachyte is a very fine-grained rock of similar constitution. It can usually be recognized, in spite of the fact that the constituent minerals are in such small particles that they are distinguished with difficulty, by its light color and light weight.

The diorite-andesite group includes diorite, sufficiently coarsely crystalline so that the constituent minerals may be distinguished, and andesite, very finely crystalline. In the diorite-andesite group, the feldspar present is of the dark variety, plagioclase feldspar. Hornblende is also present and equals or exceeds in its amount the feldspar. Quartz is also usually present, and there may be other accessory minerals. It is evident from the composition that the diorites grade into the granites, on the one hand, and it will be seen that they grade into the gabbros, on the other. When the constituent minerals are present in very tiny grains so that it is quite impossible to make out the individual components, the rock is known as an andesite. When the constituent minerals occur, any one of them in large crystals, while the rest

of them are relatively fine crystals, the rock is again known as a porphyry; and in this case porphyritic diorite or diorite porphyry.

In the gabbro-basalt group, the rocks consist essentially of pyroxene and feldspar, and the feldspar is usually of the dark variety, labradorite being the commonest form, though we do have gabbros in which orthoclase is abundant. The pyroxene in these rocks equals or exceeds the amount of feldspar present. These rocks are all dark in color, relatively heavy, and the amount of quartz present is small. Very often there are accessory minerals present such as mica in tiny flakes, particles of hematite or magnetite, and often olivine in considerable quantity. In the latter case the olivine gives the rock a distinctly greenish cast and such rocks are commonly known as green stones. Gabbro is the coarsely crystalline member of this group. Diabase is more finely crystalline. If the crystals of which the rock is composed are quite fine, the feldspar being recognizable but the accompanying darker minerals in such fine particles that it is difficult to distinguish them even with a lens, the rock is a dolerite.

The term, basalt, is used to include all of those dense, dark, igneous rocks in which the constituent grains are so tiny as to be unrecognizable. Sometimes one of the ingredient minerals will be present in coarse crystals, when the rock is known as a basalt porphyry. Basalt occurs in very large beds, covering immense areas, especially in the regions occupied by the older rocks. As the old lava cooled, giving rise to the basalt, often the mass so contracted as to break into quite regular columns, and these shattered into blocks by cross-fractures so that not uncommonly basalt has a columnar structure. A similar phenomenon is seen in beds of mud where the clay on drying cracks into polygonal masses. In the latter case the phenomenon is due to loss of water, whereas in the former it is due to the gradual contraction as the hot mass cools. Such columnar basaltic masses are famous in the Giant's Causeway in Ireland, the Devil's Pile Quarry in our western states (see also Fig. 29). Basaltic tuff is very light, spongy rock, dark in color, and correspondingly

heavier than rhyolite pumice. It was thrown out originally as coarse ash from the throat of the volcano and later solidified. If the ash were thrown out in coarse fragments and these were later cemented together, the rock is known as a basaltic breccia.

The trachytes, andesites, and basalts are so fine-grained that it is difficult to distinguish them in the field, so for practical purposes they are distinguished as felsites and basalts. If such a fine-grained rock is very dark, grayish, greenish, purplish, or black, the rock is called a basalt. If, however, the color is light, medium gray, pink, red or even dark red, yellow, brown, or light green, it is termed felsite.

Finally, the peridotites are very heavy rocks in which there is very little or no feldspar, the dominant minerals being pyroxene and hornblende together with considerable iron ore.

These igneous rocks would be largely wanting in the regions covered by the sedimentary deposits, such, for instance, as the states of the North and Central United States, were it not for the fact that the great glacier which at one time covered this region brought down with it great quantities of these rocks imbedded in its mass or riding on its surface from the regions occupied by the older rocks in Canada or the northern portions of the states bordering the Great Lakes. When the glacier finally melted and retreated, these rocks were deposited in the soil as bowlders, so that the student even in regions where the bed rock is sedimentary rock may find many samples of the igneous rocks described above by collecting samples of these bowlders.

The chief sedimentary rocks are limestone, sandstone, conglomerate, breccia, shale, slate. When shells of such animals as clams, oysters, snails, are worn to sediment by wave action, or when the hard parts of coral are similarly disintegrated and the sediment deposited in the quieter depths of the sea, then later by the pressure of overlying layers and the heat of the earth is changed to rock, the result is limestone. One marvels that the

shells of animals or corals can exist in such quantity and be so ground up as to form great beds of rock, yet the process can readily be seen now going on in many localities, as along the coast of Florida. The bed rock of that state is largely such limestone—cochina limestone, of very recent formation—and the little clam, the cochina, exists in countless hordes in the ocean along its shores. The area of the state is constantly being thus extended. The soil of the states of the Middle West, Ohio, Indiana, Illinois, etc., lies in large part on a limestone bed rock deposited in the old seas that once covered their present sites. Such beds of limestone, often hundreds of feet thick, represent the accumulated remains of untold numbers of shells and countless generations of corals (Fig. 30). But the time consumed in their formation according to the geologists mounts up into the millions of years, which is quite necessary for such a vast procession of living things.

FIG. 30.—Limestone, showing stratification

Limestone may be almost as hard as feldspar or very soft. It can always be scratched with a knife. It may be of many colors though usually it is some shade of yellow or gray. Since it is composed of calcium carbonate it effervesces with acid. It often contains fossils, the remains of animals and plants that were buried in the mud when the limestone was forming and were altered with it to stone. Such fossils show with remarkable

fidelity all the details of structure. Sandstones and shales also contain such fossils (Fig. 31).

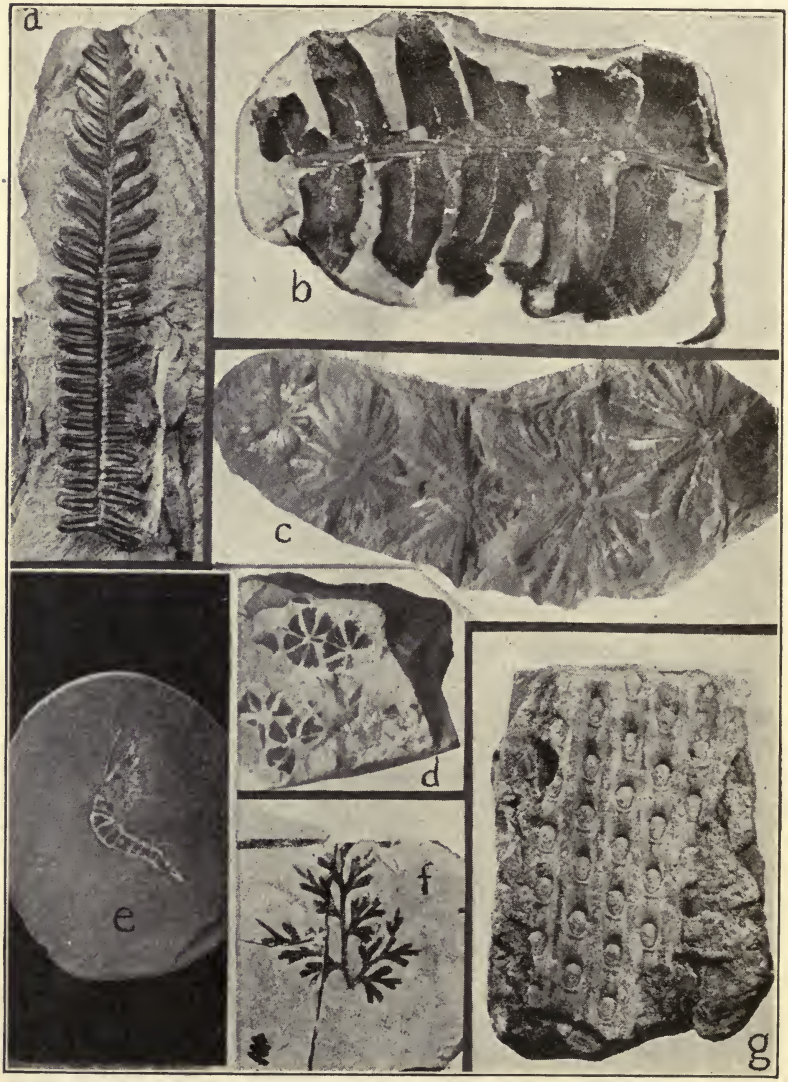


FIG. 31.—A group of fossils: (*a*), (*b*), (*d*), (*f*), fern fronds; (*c*), an equisetum; (*e*), an animal, a shrimp; (*g*), bark of *Sigillaria*.

Sandstone is composed of sand grains more or less thoroughly cemented together, and may be quite hard or very soft and friable. It often contains impurities, notably the oxides of iron that impart various colors to it, chiefly yellow or red. It is the result of the solidification of old beds of sand. Conglomerate is merely a very coarse sandstone in which the component bits are rounded, water-worn pebbles instead of sand grains. Breccia is similar, but the bits of stone of which it is formed are still angular.

Beds of clay when transformed to rock by pressure and heat form shales. They are fine-grained rocks, usually soft and split easily into layers. They give an earthy odor when breathed upon. They also vary greatly in color, depending on the nature of the contained impurities.

The soft coals are also sedimentary rocks. Along the margins of the ancient seas there occurred sometimes extensive swamps, especially at the mouths of rivers just as they exist today in deltas. In these vegetation was very rank. As the trees, ferns, rushes, and other forms matured and fell, they sank into the shallow water which covered them and prevented their immediate decay. Year after year, century after century, added to the accumulation until the lower layers were compressed into peat. So peat beds are forming nowadays in such locations. These peat beds continued to form to great depths, the crust of the earth sinking with the weight of the great accumulation. The lower layers were still more powerfully compressed by the great weight above them, and were heated from the earth's hot interior. So lignite or brown coal was formed, and this in turn changed to bituminous or soft coal as the gases and more volatile oils were driven off. Often quantities of mud were brought down by the rivers and deposited in such swamps. When compression occurred these transformed to shales. Since the clay contained much vegetable material, the shale formed from it is dark, carbonaceous shale. It often is impregnated with the oils and gases that distil off from the forming coal.

Sedimentary rocks are all deposited in layers (see Fig. 30). Throw a handful of sand into a tumbler of water and allow it to settle thoroughly. There will then be layers of sand in the bottom of the tumbler, the heavy coarse material having gone down first, the lighter, finer material following. So the débris resulting from the distintegration of shells and coral skeletons or of the igneous rocks worn to bits by the forces of erosion as it deposited in the quiet depths of the seas was sorted and laid down in layers whose constituent particles were now coarse, now fine, depending on the strength of the currents that brought them to the place of deposit. Sometimes these layers are thin; so they may readily be seen even in a hand specimen, again they are thick and are only to be noted at the quarry or rock cut.

Now igneous and sedimentary rocks may be greatly altered after their original formation by heat and pressure. When a new lava stream forces its way up in the cracks of older rocks it alters the rock with which it comes in contact. As old beds of rock are heated and subjected to terrific strains and compression as they are bent and upheaved when mountain chains are formed they are much changed. This process is known as metamorphism and the rocks so altered as metamorphic rocks. Thus limestone changes to marble, sandstone to quartzite, shale to slate and schist, bituminous coal to anthracite, while igneous rocks like granite change to gneiss or schist. Gneiss contains the same constituent minerals as the volcanic rock from which it is derived, but the component grains are flattened and forced to lie with their long axes in the same direction, thus giving to gneiss a somewhat stratified appearance. Schists have the constituent particles even more flattened, so they are scalelike. They are often so soft they may be crumbled with the fingers. They are named from the dominant mineral present, as chloritic schist, micaceous schist. In slate the layers of the rock are easily separable. Sometimes they are very thin, as in the familiar school slates. Quartzite is very hard, like quartz. It also breaks with a conchoidal fracture but shows the granular structure of

the sandstone, though the sand grains are indistinct through partial fusion. Marble is crystalline, fairly hard though still scratched with a knife, and effervesces with acid, though not as violently as limestone unless the latter contains much silica, a siliceous or cherty limestone.

Commercially the most valuable of all the sedimentary rocks is the coal (Fig. 32). We are very fortunate in possessing such vast quantities of it in this country. It is estimated that we

FIG. 32.—Entrance to a coal mine

have mined some 14,000,000,000 tons thus far in our history, and that we still have left 17,000,000,000 tons of anthracite, 1,500,000,000,000 tons of bituminous, and 2,000,000,000,000 tons of lignite, a coal of inferior quality but still usable. We are using our coal at a much faster rate than ever before, for the industrial demand for it is ever increasing. In 1921 we mined nearly two-thirds of a billion tons. Just how long the available supply will last it is very difficult to say or even to make an approximate guess as there are so many factors involved. Some of the coal

is so deep down or in such narrow seams it can scarcely be mined with profit. Then other forms of energy production may take the place of production by coal. We are already using water-power very extensively.

Out of every 1,000 tons of coal, industry uses 350 tons; railroads, 250 tons; domestic heating and cooking, 165 tons; coke, 130 tons; fuel at the mines, 35 tons; gas works, 10 tons; and we export 60 tons. Our methods are still so wasteful that less than half of the energy in the coal actually dug out of the earth gets to the consumer in available form.

Oil and gas are also derived from the coal measures. Since oil was struck in 1859 we have used 5,467,000,000 barrels, nearly 50 per cent of the estimated supply, and we are using it at the rate of over 500,000,000 barrels annually, so that the available supply of oil that can be pumped out of the earth in the United States will necessarily soon be exhausted. Fortunately, there are almost limitless supplies available in the oil shales from which it can be distilled. This is a more costly process and oil prices probably must rise, but still there is no danger of an oil famine for generations. Indiana alone has oil shales estimated to yield 100,000,000,000 gallons.

We are burning about 800,000,000,000 cubic feet of natural gas annually purposely, and there are many millions of cubic feet going to waste as it escapes into the air or burns at wells where it is not being utilized.

CHAPTER III

THE CONQUEST OF THE AIR

When I bestride him I soar, I am a hawk.—SHAKESPEARE

Primitive man was forced to find or produce food, to protect himself from the inclemency of the weather and from his enemies, and to transport himself and his belongings to new territory when he had exhausted the resources of one spot. Production, transportation, and self-defense are still problems of prime importance in our modern life.

At first man found or produced what he needed by his own unaided efforts. He made things by hand. His chief defense was the strength of his bare arm or the speed of his legs. He was his own beast of burden. In time he discovered how to domesticate plants and animals, how to use tools and machines. Then production, transportation, and defense were made relatively easy. The history of man's progress along these lines, of his inventions and their effect on social adjustment and organization, is the most interesting and important phase of the history of the race.

Much of the subject-matter to follow will deal with the matters thus briefly outlined. The presentation will not follow the logical order here suggested, however, but will begin with such toys and appliances as usually enter into the pleasurable experience of childhood, and proceed through the scientific principles elucidated by them to an understanding of some of the most valuable inventions man has made to aid him in the task of making the forces of nature subservient to his needs.

No chapter in the history of man's subjection of Nature has been more replete with thrilling incidents than that which deals with the conquest of the air. Two major lines of endeavor have

characterized the attempts to utilize the air as a means of furthering his purposes: (1) to harness the winds to provide power for his machines; (2) to use the air as a medium of transportation. Under the first heading may be mentioned windmills and sail boats; under the second, kites, aeroplanes, and balloons.

Who the inventive genius was who first devised and flew a kite we do not know. But probably it was some Chinaman, for kites have been known in China and Malaysia for a very long time, even before historic times; they are used there for decorative effects at the numerous festivals. Not only the tailed variety but also the tailless sorts are made, and these latter of many curious designs—fish, birds, and geometrical figures of pleasing shapes.

Kites have been largely playthings for the race until very recent times, although occasionally some keen ancient mind caught sight of their serious uses.

The first really serious use of kites that is historically authentic occurred in 1749 when Dr. Alexander Wilson, an Englishman, and Thomas Melville, an American, raised kites high up in the air with thermometers attached to them to get the temperature of the upper air. Since then kites have been used extensively for carrying up thermometers, barometers, hygrometers, anemometers, and other scientific instruments to get records of the conditions up among the clouds. Such facts are of service in a better understanding of the sudden changes and probable conditions of the weather. Many of the United States Weather Bureau stations are provided with kites which are regularly flown, carrying up self-registering instruments to collect data. Kites have been sent for such purposes so high that the recording instruments showed a barometric pressure of only 4 inches and a temperature of $-87°$ C. Remembering that the air pressure at sea-level is about 30 inches on an average, it is evident that the kite had soared well above the great bulk of the air.

Kites have been used to take up cameras to get a bird's-eye view of the underlying territory, to lift men as observers, and

to carry messages out of besieged cities, but these things are all better done by small balloons, which will be considered later.

Lawrence Hargrave, of Sidney, New South Wales, invented the box kite. This kite, it was discovered, has greater lifting power than a kite that presents only one plane surface; besides which it flies much more steadily, needing no tail. This discovery was very suggestive to those inventors who were working on the aeroplane at that time. In fact, the principles underlying the flight of a kite are the ones that make possible the flight of the aeroplane, and to understand why a kite flies is to understand in large measure the principles upon which operate all those machines of men that depend on currents of moving fluids such as winds and streams of water for their motive or sustaining power.

Every lad who has flown a kite knows it will fly well only in a wind. By running swiftly while you hold one end of the long string to the other end of which the kite is attached, you may make the kite rise a bit on a still day, but it drops back to the ground again the minute you stop running. While running you pull the kite through the air, but when the wind is blowing the air streams past the kite, sending it up. But just how does it operate to accomplish this?

When the wind is blowing, particles of the air in their forward movement strike against the face of the kite. If the kite were not held by the string, it would just blow along on the ground in the direction in which the wind is blowing, like a loose sheet of paper. But the string is so tied to the kite by means of the bridle that the kite's surface stands inclined to the wind, and so the moving air particles strike the kite at an angle, hitting a glancing blow. When that happens the force with which the wind strikes the kite is broken up into two components, one of which lifts the kite up into the air.

A simple experiment may be readily performed to illustrate the law of the composition and decomposition of forces. Set three small nails into a large drawing-board or the floor at the

points of a triangle with sides at least 15 inches long (see Fig. 33). Slip the ring of a spring balance on to each nail. Tie a string to the hook of each spring balance, and then tie the other ends of these strings together, making the tie so that each scale will register some pull. It is evident that the amount registered on any one scale is the resultant of the pulls of the other two.

The relation between these forces may be graphically calculated as follows. Lay a good-sized sheet of paper on the

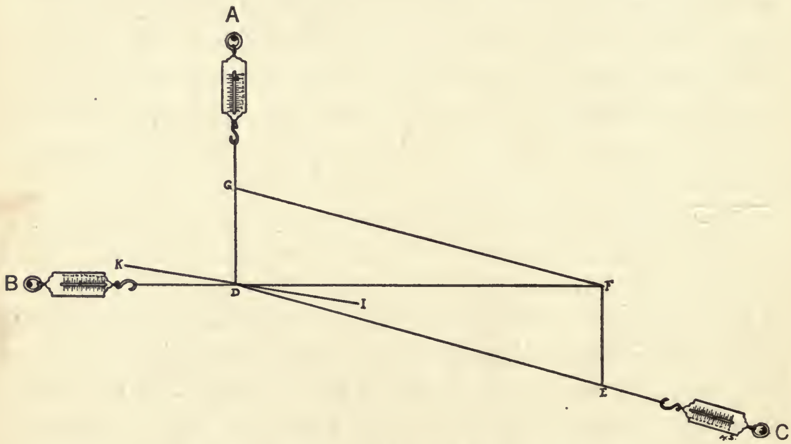


FIG. 33.—Diagram of the decomposition of forces
GD=1 in. Scale *A* shows 1 lb.
DE=4 in. Scale *C* shows 4 lb.
DF=$3\frac{7}{8}$ in. Scale *B* shows $3\frac{7}{8}$ lb.

drawing-board underneath the three strings, its center about under the knot. With a ruler draw lines immediately under and parallel to the three strings, the three lines meeting immediately under the central knot (*D* in the figure). Suppose the scale at *A* measures 1 pound, the scale at *C*, 4 pounds. Lay off on line *DG* 1 inch, on line *DE*, 4 inches. From point *G*, 1 inch from *D*, draw a line parallel to *DE*, and from point *E*, 4 inches from *D*, a line parallel to *DG*, thus making a parallelogram. Continue the line *BD*, and it will make a diagonal of the parallelogram. Its length in inches will be the pull on the scale at *B* in pounds.

Thus knowing the strength and direction of the pull of the two combined forces, the resultant may be determined; or knowing the resultant and the direction of the pull of the component forces, the latter may be determined.

Forces acting along *DE* and *DG* in unison on point *D* in the direction of the points *C* and *A* combine to produce the effect of a force acting along line *DF* which is counteracted by the equilibrant pull on the scale at *B* along line *BD*. As calculated above, the magnitude of the operating forces and the resultant effect are in proportion to the sides of the parallelogram and to the diagonal.

Conversely, suppose a particle of air is moving swiftly along line *BD* from *B* toward *D*, and at *D* it strikes the surface of the kite *KI*. It hits the kite a glancing blow at *D*, and flies off along *DE*. But the force of the blow at *D* is resolved into two factors, one of which acting along *DG* lifts the kite. Successive air particles as the wind blows hit repeated blows. The combined effect sends the kite up. If the length *DF* represents the intensity of the force striking *D*, it will be resolved into two components acting along *DE* and *DG* proportional to the lengths of these lines, and the sum of the components will, of course, be equal to *DF*. The wind is resolved into such factors only when the string holds the kite against the wind.

The kite mounts in the air as the string is played out until the down pull on the string and the weight of the kite equal the factor *DG*. If the bridle is so adjusted that the kite lies at an acute angle to the direction of the wind, the factor *DG* will be small, the kite will fly almost directly overhead, and the pull on the string will be slight. If, however, the bridle is adjusted so the kite makes a relatively large angle to the wind, the factor *GD* will be great. The kite will pull hard on the string and will sail off to a distance, but will not mount very high. It is evident that in a light breeze the bridle must be adjusted as in the second case to get the kite to go up at all, for it will need much of the force of the wind to raise the kite and its attached string. But in a good stiff breeze the attachment indicated in the first case

will be used to insure the kite carrying high into the air, nearly straight overhead.

Directions for making and flying the various types of kites, the ordinary tailed kite, the tailless bow, and box kites (Fig. 34), are given in the *Field and Laboratory Guide in Physical Nature-Study*. A method for making the odd bird kite will be given here.

Cut four very thin strips of bamboo or cedar 3 feet long. Fasten two of these together to make a figure 8 with one loop three or four times the size of the other. This may be done by binding the overlapped ends and the intersection with stout thread. Similarly, fasten together by their ends the other two strips laid parallel and then spread their centers apart a foot. Bind them, so spread, to the figure 8, fastening the mid-point of one strip to the neck of the 8, the other one to the sides of the large loop. The large loop of the 8 makes the frame for the body of the bird, the small one for the head. The side extensions are the wing frames. Cut two thin 15-inch strips of bamboo and fasten one end of each to the sides of the larger loop of the 8, halfway from the wing frame to the lower end. Cross them and tie the crossing to the mid lower end of the loop so their free ends spread fan-shaped beyond the 8 for the frame of the tail. Fasten a taut string between their free ends.

Now lay the kite frame on a large sheet of tissue paper. Cut from it a rectangular strip as long as the kite is wide from tip to tip of the wing frames and 3 inches wider than these at their widest point. Run paste all around the edges of this strip. Place the kite frame on it and turn the edges of the paper over the wing frames just far enough so the edge will stick to the paper. This will allow the paper to bag more and more out to the wing tips, where one edge of the paper will be stuck to the opposite edge.

Cut the sheets to cover the head frame, and the body frame 2 or 3 inches larger all the way around than the frames, and stick the edges over the frame as on the wings, so the paper on both head and body will bag in, in the same direction as on the wings.

A triangular piece of paper is pasted flat on to the tail frame, its edges overlapping the frame.

When the kite is dry, with small brush and ink paint eyes and beak on the head, feet and legs on the body, and radiating lines on the tail to suggest spread-out tail feathers.

To make the bridle to which the string is attached, tie three 18-inch lengths of string, each by one end, on to the frame, one at the neck and one on each side where the wing frame crosses the body frame. Then tie the other ends of these together, making the strand to the neck about 3 inches shorter than the other two, which are equal in length. The string on which the kite flies is tied to the point where these three are knotted together.

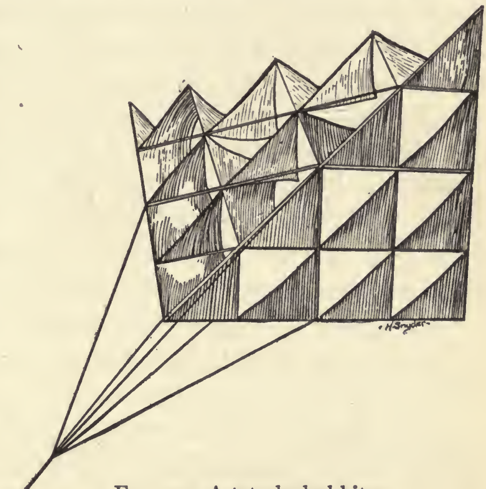


FIG. 34.—A tetrahedral kite

The ordinary kite must needs have a tail. The wind is always fitful and gusty, blowing with changing velocities and constantly shifting its direction as one flaw comes from one direction, another from a different point of the compass. The kite in such a gusty wind is buffeted first to one side, then to the other, and so tends to bob around. As the wind suddenly increases in intensity, the kite rises quickly, pulls hard on the string, and turns a somersault. The tail acts as a stabilizer, for it makes an inert weight hanging below the kite which the kite must carry along with it. A body at rest forcibly resists movement as a force acts upon it to move it. It has inertia. So if the body is in motion, because of inertia, it tends to remain in motion in the same direction until some force acts upon it to deflect it

or to bring it to rest. The inertia of the tail tends to restrain the kite and keep it from bobbing about erratically.

When a kite is built of several plane surfaces set at varying angles to each other as in the box kite or the tetrahedral kite (p. 83), or presents curved surfaces to the wind as in the bow kite or bird kite, the gusts of wind strike these at such varying angles that the kite is impelled in a dozen different directions simultaneously, with the result that these various impulses work against each other, and so the kite remains quite steady in the main air current. Such kites, therefore, fly well without a tail.

Kite-flying may be made to afford a great deal of amusement and incidentally much experience with winds that gives the pupil a real appreciation of their power and a first-hand acquaintance with some of the problems involved in their utilization for man's purposes. Indeed, it is a sport followed in many countries by adults. It requires considerable skill to fly your kite higher than any of your competitors. Tandem teams of box kites will fly to great heights. Send up a box kite letting out 200 feet of string, then fly another one on 50 feet of string and fasten the free end of the string to the string of the first kite. Let out more string and fasten on another.

You may slip colored paper windmills or disks of paper on to the string of your kite, passing the latter through the hole at the center of the disk or windmill and so let them go sailing or twirling up to the kite. You may draw a face on your kite or the head of an animal. A kite that is covered with black paper on which are pasted tissue-paper circles for the whites of the eyes, red tissue-paper nostrils and lips with white paper teeth is a conspicuous and comical object in the air as it goes bobbing about.

We boys used to fasten a sharp, narrow strip of tin on to the kite string, then try to cut the other fellow's kite string, and so see who could keep his kite up longest without accident. I remember, too, our ambitious plan of building a great, big kite. It was of the ordinary type but extraordinarily large—15 feet

long and 10 wide. It was covered with heavy express paper. Its tail was made of old rope, abandoned at the mine but still strong enough for our purposes. We used small rope to fly it. We found it necessary to rig a windlass on top of an old stump on the hill behind our house to wind the big kite in. I shall never forget the demonstration the monster gave of its lifting power as it pulled me off my feet in one of our early attempts to fly it.

Civilized man has always been envious of the flight of birds. It seemed strange that the lords of creation should be condemned to progress by such a tiresomely slow method as walking, while birds and even lowly insects mount the blue heavens on beating wings and soar over the earth with speedy flight and wide vision. So mythology has supplied its heroes with a winged horse, a magic carpet, wings like those of Icarus, or some such contrivance by which they, in story at least, might move swiftly from place to place as do the birds.

It is related of Archytas, a Greek who was famous for his knowledge of mathematics and mechanics, that he made a mechanical contrivance resembling a pigeon and that like a pigeon it could fly. But this is very doubtful, and the tale probably belongs with other Greek myths indicating desire rather than achievement. Nevertheless, it does show that even these early natural philosophers had it in mind to devise a flying machine.

One Simon, a magician in Rome in the days of Nero, so legend says, actually went up in the air by means of some sort of a contrivance, just what we do not know. But he fell and was killed, and the populace credited his performance to his alliance with the devil.

It is apparently authentic history that a Benedictine monk Elemus, at Malmesbury, England, in the eleventh century, built a machine with wings and tried it from a tower. He glided for a short distance, but, lacking the skill to balance his appliance, fell with disastrous results.

A Scotchman, Albert Damien, undertook to fly in 1508 with a pair of wings made to fit on to his arms and feathered with

chicken feathers. He was so confident when his wings were in the making that they would carry him readily that he proposed to fly across the English Channel. When he tried them out, however, jumping from an elevation for a preparatory flight, he found flying no easy art and fell, breaking a leg and losing his ambition. Besnier, in France, in the reign of Louis XIV devised an apparatus of four folding planes that spread out on the down

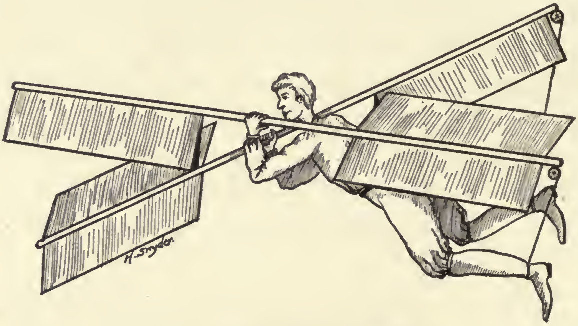


FIG. 35.—Besnier's flight apparatus

stroke and closed on the upstroke (Fig. 35). They were carried at the ends of light rods that balanced on the shoulders and were worked by arms and legs. De Bacqueville, another Frenchman, in 1744 tried to fly with four large planes, one attached to each

FIG. 36.—Marquis de Bacqueville's wings for flight

hand and each foot (Fig. 36). His idea was that one could swim in air as in water, since both are fluids, provided hands and feet could be sufficiently enlarged. He tried his scheme, jumping from a balcony overlooking a river, but fell into a passing boat.

These are only a few of the more famous persons who all down through the centuries have tried to fly by crude wings operated by their own weak muscular energy. They were doomed to failure, for it is estimated that a man can exert such continuous muscular energy only to the extent of a third of a horse-power (see p. 183) while it would take some two horse-power to operate wings with sufficient power to lift him from the ground.

There followed these first foolhardy attempts at flight, without knowing anything of the principles underlying the process, a period in which an attempt was made to get at the facts and discover scientifically the principles. Sir George Cayley, an English engineer and scientist, as a result of his study and experiments, suggested the use of a steam engine to furnish motive power for the flying machine and that the engine be made to drive revolving propellers. He further advised that the wing planes be curved from front to back instead of being flat, so as to increase the lifting power. He predicted that a tail plane would add materially to the stability of the machine. These suggestions, published in *Nicholson's Journal* in 1809–10, were not incorporated into an actual flying machine by Cayley. It was not until Henson and Stringfellow, an Englishman and an Australian respectively, built a model aeroplane in 1845 that any of them took concrete form.

But while Cayley did not build a flying machine he did something that, at that stage of the development of air craft, was more important. About 1797 he built a glider, as we should call the appliance now, and experimented with it. It was really a large, light plane like a kite but not kite-shaped. Cayley thought that, if you can raise a kite, a small plane with its attached string and tail, into the air, a big plane might raise itself and a man if he would run into the wind with it, holding it tipped up slightly at the front so the wind could get under it and exert its power. Cayley's glider actually worked and lifted him from the ground, carrying him some distance.

The glider has played an important part in the development of the aeroplane, for it was quite necessary that some skill should be achieved in balancing the glider before it was possible to fly in an aeroplane. Without such skill an aeroplane might be made to rise, but it would dash itself and its occupant to almost certain destruction. The Lillienthal brothers in Germany, Santos-Dumont in France, Chanute at Chicago, and the Wright brothers at Dayton, Ohio, became quite expert in balancing themselves on their gliders, and succeeded in making fairly long flights. Lillienthal, by taking advantage of ascending air currents, occasionally rose above the elevation from which he started

FIG. 37.—Lillienthal's glider

(Fig. 37). Santos-Dumont had his glider towed by a boat after the manner of a boy running with a kite. Otto Lillienthal met his death when he tried to fly in a glider to which an engine had been added. Santos-Dumont and the Wright brothers were more fortunate, although they were not the first to go up in an aeroplane carrying a man, as will be related below.

Not only did the glider help in the development of the aeroplane, but the experience gained in flying aeroplanes has in turn developed skill in balancing and in making adjustments to the air currents that have enabled men to make sustained flights in gliders. H. P. Henzen, a student at the Hanover Technical School, flew for three hours and a few minutes in an engineless

glider, taking advantage of the air currents to keep him in the air. This was in the summer of 1922. The accompanying picture shows one of the French contestants at the gliding contest at Clermont-Ferrand. He was in the air two minutes, thirty-one seconds, in this particular flight (Fig. 38).

FIG. 38.—A French glider in flight over the field at Clermont-Ferrand. Courtesy of the *New York Times*.

Three methods of getting a heavier-than-air machine to rise and move through the air have been devised. Naturally, the first method was by means of beating wings like those of a bird. A second was by the use of a plane like that of a kite, which, instead of passively flying on the wind, should be driven

by a propeller through the air, cutting it so as to force itself up as well as forward. Third, just as a propeller drives a boat through the water, so it was thought might a propeller blade, rapidly turning, screw itself and the attached machine up into the air; then possibly a second propeller could drive the machine in the desired direction.

Now Cayley not only tried the glider successfully, but he was apparently the first to make a helicopter, as this last-named device is called. Truly it was only a toy affair, but it contained the germ of an idea from which much is yet anticipated. The directions for making a simple flier on the principle of the helicopter are given in the *Field and Laboratory Guide in Physical Nature-Study*, page 31. Helicopters have recently been built and flown with success, carrying both pilot and passenger. They have this advantage over the aeroplane, that they can rise straight up and do not need a large field from which to start or on which to land.

M. A. Penaud, a Frenchman, in 1865 built a toy on the principle of a flying bird, and it worked, the first successful machine of its type. Later (in 1874) he built another model, a miniature aeroplane, the motive power of which was twisted strands of rubber. This worked even better than his orthopter.

Herbert Wenham, an Englishman, coined the word "aeroplane" (1868) and applied it to the glider. He had the idea also that such a glider could be forced to rise and carry a man if an engine could be mounted on it. He was the first to suggest that two planes mounted one above the other in an aeroplane would have greater lifting power than the single plane.

The first aeroplane actually to carry an engine and fly was a model built by Stringfellow, the Australian. He was a skilful mechanic, and his engines were exquisitely built. He and Henson had worked together to plan such a flying machine, but it was Stringfellow who actually completed the work. It was in 1845 that he finished his $8\frac{1}{2}$-pound model, the engine and boiler making up 5 pounds of this weight. This model was a monoplane, and

it really flew. Later he built several other models; one, a triplane, was exhibited in London in 1868.

About 1881 Horatio Phillips built the first full-sized aeroplane. He believed that many narrow planes would give greater lifting power than one broad one, so he rigged fifty planes 22 feet long and only 1½ inches wide on a frame so they looked like a large Venetian blind. Each plane was curved from front to back as Cayley had suggested, though the hump of the curve was not at its center, but near the front edge, an improvement that Phillips devised. This machine of Phillips was mounted on wheels that ran on a track, and it was held down so it could not fly off and wreck itself. It registered a lift of 72 pounds besides its own weight.

Sir Henry Maxim, of Maxim gun fame, was the next to build an airship. It was a big biplane, 105 feet from tip to tip of its wing planes. Its four engines each developed 180 horse-power. They ran two wooden propellers, canvas-covered, that were 18 feet long. This machine had a small horizontal plane in front that could be tilted up and so start the aeroplane on its rise from the ground. It also had a vertical tail plane that was movable and could serve as a rudder. Both these additions of Maxim's were valuable contributions to the structure of the aeroplane that have been retained, more or less modified, in later types. This machine of Maxim's ran on a track also and was held down by guide rails. It developed so much lifting power, however, that it broke away, raised itself from the ground, toppled over, and was wrecked.

Clement Ader, a Frenchman, was working on the aeroplane about this time. He built several machines with batlike wings, the cloth cover stretched on bamboo and hollow wood-spar frames. His propellers were four-bladed ones. His machine ran on wheels on the ground and was free to rise. He called the machine an avion. In 1890 it actually rose into the air, covering about 50 yards. It was wrecked when it landed. The French government gave him a generous grant to continue his experiments

and in 1897 an improved avion rose and skimmed over the earth for 300 yards, the first successful ascent of a heavier-than-air machine with a man on board. One of Ader's machines is still exhibited at the Institute of Arts and Sciences in Paris. This ascent could hardly be called a successful flight, for the aviator was at the mercy of his machine rather than having it under control. It was badly damaged when it descended. It remained for those men who had acquired skill in balancing the gliders to make the first real flight. Before describing their experiences, however, mention should be made of the work of an American inventor, S. P. Langley, then secretary of the Smithsonian Institution at Washington.

He began experimenting in 1887 with the avowed purpose of producing an aeroplane. He made many models, powered with rubber bands, that flew successfully. He was so encouraged that he made some larger models that were driven by steam, and these flew also; one especially made flights of nearly a mile. The United States government then put funds at his disposal to build a large machine. This was provided with a gasoline engine and tried in 1903. It was the first aeroplane to carry a gasoline engine—a distinct advance in the power plant of the aeroplane. The machine carried a weight equal to that of a man as pilot. It was launched from the deck of a houseboat on the Potomac River, but the tip of one wing caught on a wire stay on the boat, and the aeroplane toppled over into the water as it rose from the deck of the boat. Langley's funds were now exhausted, so the machine was housed as a curiosity in the Museum of the Smithsonian Institution. It is interesting to note, however, that this machine was taken out and flown by Orville Wright in 1914 (Fig. 39). This, however, was after the inventor's death.

Meanwhile Orville and Wilbur Wright, of Dayton, Ohio, had been learning to use the Chanute biplane glider and had altered and improved it. The fixed tail of the Chanute glider was replaced by a plane that was movable so it would steer the biplane up or down. The wings were also capable of movement so that

they could be warped a little, throwing the front edges up or down as necessity required. In all experiments with the glider the chief difficulty encountered was found to be the balancing of the plane. The sea of air in which the pilot launches his glider is not a calm sea but is full of waves and cross-currents. Every large obstruction like a hill on the surface of the earth throws the wind up into a billow. The wind does not blow steadily but in gusts and flaws that come first from one point of the compass and then from another. Lillienthal had

FIG. 39.—Langley's aeroplane

endeavored to balance his machine by movements of his body. He supported himself in his machine by resting on the frame with the supports under his arms, leaving his body from the shoulders down free to swing in any direction. If a gust of wind tended to lift one wing of his machine he threw his body over toward that wing, so shifting his weight as to bring the wing back again into its horizontal position. In such a position his body offered large surface to the wind that tended to retard the flying of the machine. The Wright brothers were accustomed to lie on the lower plane, thus reducing the air resistance of their bodies, and near at hand were the levers that controlled the

warping movements of the plane. When a gust of wind tended to throw up one wing, the front edge of that wing was turned down while the front edge of the opposite wing was turned up. As the wings cut the air in this new position, the machine regained its balance.

Anyone who has undertaken to ride a bicycle will appreciate in some measure the difficulties encountered in learning to balance the aeroplane. In balancing the bicycle one has only to avoid falls to right or left. If you tend to tip over to the right you turn the front wheel to the right and so bring the line of support of the two wheels underneath your center of gravity. In the aeroplane, however, you are not riding on the solid ground but in unstable air. You are likely to be buffeted by the winds that blow up and down as well as by cross-currents that come from right or left. The Wrights, however, became very skilful in flying their gliders, and then they attached a gasoline engine to drive such a glider. This engine operated two propellers by means of chains. They launched their machine from an inclined rail, a rather bungling contrivance for getting under way; but in December, 1903, they made their first successful flight. This was made in an out-of-the-way place in South Carolina. After demonstrating to their own satisfaction that they could really fly, the machine was packed away while they were getting patents on their various devices.

French inventors were also busy in building and perfecting aeroplanes. Santos-Dumont, after becoming somewhat skilful with the glider, undertook flights with an aeroplane which was constructed for him by the Voisin brothers. This was in 1906. In November of that year he made a flight of some 230 yards. He did not follow up his success, however, but abandoned this machine and undertook the construction of an aeroplane which should rise from the water. In 1907 another Frenchman who later became famous in air work, Henri Farman, began practice with a Voisin machine and before the end of the year made a flight of nearly half a mile. Another French aviator who was

to become famous, Louis Blériot, was practicing with a machine of his own construction. All these French machines were provided with light wire wheels by means of which they could run along the ground until sufficient speed was attained to carry them into the air. In 1908 Wilbur Wright took his machine to France to demonstrate its abilities, and astonished the French aeronauts by his easy control of the machine. He was able to climb rapidly, turn with precision, and dive easily. More than that, he remained in the air for a much longer time than the French pilots had been able to, flying steadily for more than two hours and a half.

The year 1909 was notable in aeroplane achievements, for there occurred near Rheims the first International Meet. Several new types of aeroplanes made their appearance, and there were a number of exceedingly interesting contests. Hubert Latham, an Englishman, won the prize for the greatest height achieved—500 feet. He drove an Antoinette biplane. Farnam won the endurance test, remaining in the air for three hours and four minutes. He was flying a machine of his own design, a biplane with a new type of engine, the Gnome. In this engine the cylinders revolved, thus cooling themselves as they whirled rapidly through the air. One of the great difficulties which the air man had encountered up to this time was the overheating of his engine. Glenn Curtis, an American, won the speed contest with a biplane of his own construction, achieving 47 miles an hour.

When one realizes that the first successful flight in an aeroplane was made in 1903, and when comparison is made of the achievements of this first International Meet and present-day accomplishment, the remarkable celerity with which the aeroplane has been developed is truly wonderful. J. A. MacReady, an American army officer, in 1921 attained a height of 40,800 feet. At such a height the air is so rare and the temperature so low that the aeroplane and aviator must both be equipped with special devices. A condenser is added to the engine equipment

so as to deliver air to the engine cylinders at normal sea-level pressure. The aviator wears electrically heated clothing and a mask which is connected with an oxygen tank so he may be supplied with the necessary oxygen for respiration. In the flight of Mr. MacReady, when in 1920 he attained a height of 36,020 feet, the valves of his oxygen apparatus failed to work properly as they rose into the very thin air. The aviator lost consciousness; the machine, out of control, fell, but, luckily, MacReady regained sufficient consciousness at a height of some 2,000 feet to get control of his machine and make a landing.

In the Pulitzer trophy race at St. Louis, Missouri, in 1923 an American, Lieutenant A. J. Williams, won, driving a blue Curtiss navy plane over the 125-mile course at a speed of 243.67 miles an hour. On a short, straight course a speed of nearly 400 miles an hour has been achieved. Already the Atlantic has been crossed in a single flight. Furthermore, the aeroplane has been developed to the point where it is commercially valuable. Regular mail routes are now established both in Europe and in this country. New York mail is carried to San Francisco, and the Pacific Coast mail back to New York. New York, Cleveland, Chicago, Minneapolis, St. Louis, Omaha, San Francisco, Portland, are all connected now by the regular air-mail routes. Regular passenger service is established. The time from Paris to London is two hours. The passenger rides in a coach that is quite as stable, comfortable, and luxurious as a Pullman car.

A simple but very effective type of aeroplane is made as follows: Cut a $\frac{3}{8}$-inch square strip of white pine 22 inches long (or use a piece of bamboo $\frac{3}{8}$ inch wide). This strip should be straight-grained and free from knots, for it serves as the backbone of the machine and must bear the strain of the twisted rubber bands that serve to run the propeller.

Cut a strip of tin $4\frac{3}{8}$ inches long and $\frac{3}{8}$ inch wide. Bend it 2 inches from one end into a sharp V. Holding it with the long arm to the left, bend this long arm 1 inch from its end so that the

bent portion turns to the right and lies at right angles to the rest of this side of the V. Bend the other arm of the V in the same direction 1 inch from its end so that the bent portion is parallel to that of the first arm of the V. These two parallel parts should now be bound tightly with coarse linen thread to the end of the backbone, their long axes coincident with its long axis. This end is the front end of the machine. Near the tip of this V and in its midline punch a hole through both sides so that a stiff wire axle that bears the propeller may run through the holes parallel to the long axis of the backbone.

For the skids, cut two thin strips of bamboo $\frac{1}{8}$ inch wide and 6 inches long, and one $4\frac{1}{2}$ inches long. Bind these together with the linen thread in the form of a triangle, letting their ends overlap $\frac{1}{4}$ inch. Bind this to the backbone 1 inch back of the tin propeller bearing, the juncture of the two long sides above the backbone and on the opposite side from the point of the tin strip. Let the plane of the triangle be at right angles to the backbone. Cut two more such thin strips 5 inches long and bind one end of one to the midpoint of one of the long sides of the triangle, the other end to the backbone about $2\frac{1}{2}$ inches back of the point to which the apex of the triangle is affixed. The other strip will be bound to brace the other side of the triangle in a similar way.

Cut two more thin strips 5 inches long. Set one on each side of the backbone 1 inch from its rear end at right angles to the backbone and perpendicular to the base of the forward triangle. Bind them on tightly at their midpoints. Fasten a brace of bamboo from the upper end of this pair of strips to the backbone about 3 inches in front of the point where the pair of 5-inch strips is bound to it.

Cut three strips of bamboo 3 inches long and so thin that each can be bent into a U over the end of the finger without breaking. Bind one of these by its ends to the lower end of each side of the bamboo triangle and one to the lower end of this last support near the rear, the plane of each U parallel to the longitudinal axis of the backbone. These three loops form skids on which

the aeroplane stands, and they slip along the floor or sidewalk as the machine takes flight (Figs. 40 and 41).

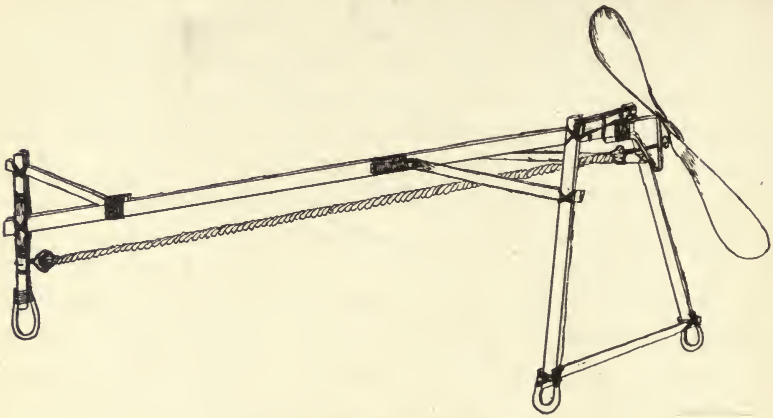


FIG. 40.—The aeroplane frame

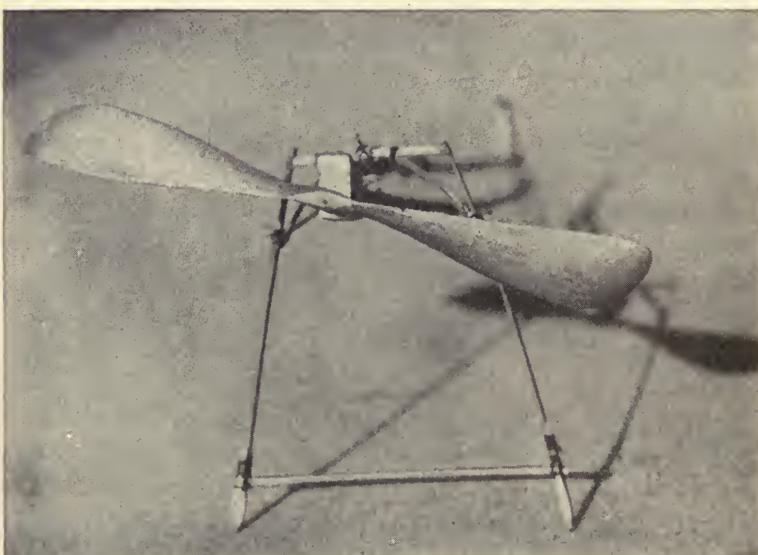


FIG. 41.—Front view of aeroplane frame

Shape a 9-inch propeller out of the tin of a coffee can similar to the one cut for the flier (p. 90). If the longitudinal axis of the propeller is made to coincide with the length of the can, the curve of the tin will give about the right curve to the propeller after it is bent according to the instructions. Or a propeller may be fashioned out of white pine, white wood, or cedar that is straight-grained and free from knots. Cut the block of $\frac{7}{8}$-inch stuff 9 inches long and 2 inches wide. Bore a hole at the middle of one broad face just large enough to take the stiff wire that must be used as the axle for the propeller. Draw a square 1 inch on each side, its center coincident with the hole, its sides parallel to the sides and ends of the block. Draw lines from its corners to points on the adjacent sides 2 inches from each corner of the block. Cut away the sides of the block along these lines. Mark the ends of the block according to the diagram (Fig. 42), and saw away the wood from both sides of the diagonal strip down to the central square. By sandpaper held over the thumb to give a curved surface or with bits of broken glass having rounding edges work away the wood of the blades to make them thin and curved according to the heavy line of the diagram. The blades may be shaped so that their outer ends are rounded similar to these of the flier. Cut away the corners of the central block so that it joins the blades in flowing surfaces.

FIG. 42.—Diagram of the end of the block from which a propeller is cut.

Pass one end of a 6-inch length of stiff wire through the hole in the center of the propeller so that it protrudes $\frac{1}{2}$ inch. Bend this protruding end down to the wood center and tack it securely. If the tin propeller is to be used, stick the wire through one hole $1\frac{1}{2}$ inches and bend it so that the end can be thrust back through the other hole and twisted on the long wire so as to hold the propeller securely. A short block of wood set on the back of the

propeller between the holes and included in the loop of wire will help to hold the propeller solidly.

Put a flat, good-sized bead on the free end of the wire, then pass the end through the holes in the tin propeller bearing and make a triangular loop on the wire just back of the bearing to take the strands of rubber that make the motor. The bead used helps to reduce friction. Make another small triangle of wire and bend the free ends so that they can be bound securely to the front of the rear skid strut about 1 inch from the backbone. Pass the long strand of rubber that can be bought for this purpose through this rear wire loop, then through the one on the rear end of the propeller shaft, and so back and forth until about ten strands are laid on. Tie the ends of the rubber together to complete the last strand.

To make the planes, cut two thin bamboo strips $\frac{1}{8}$ inch wide and 22 inches long and two 5 inches long, and bind their crossed ends together so as to make a rectangular parallelogram of the strips that will serve as the frame for the forward plane. In the same way make the rear frame for the plane 10 by $4\frac{1}{2}$ inches. Cover the frames with strong but light paper, folding the paper over the edge of the frame 1 inch and gluing it down. Fasten the forward plane horizontally to the backbone, its long axis at right angles to the latter, its front edge just back of the struts that support the forward skids. Tack it lightly in place with thread. The rear plane is fastened similarly with its hind edge just in front of the brace that supports the rear strut. When the planes are in place balance the machine on the forefinger placed under the backbone near its center. If the planes do not lie horizontally but tend to dip to one side or the other, their position may need to be changed slightly. When they do balance well, fasten them securely in place, daubing the bindings with glue so that they will not slip. Guy threads may then be run from the outer tips of the planes to the adjacent struts to make them sufficiently rigid to stand the strains of flight (Fig. 43).

Observe which way the propeller, which is at the front of the machine, should turn in order to carry the machine in the air, then turn it about 150 times in the opposite direction. Head the aeroplane into the wind, set it down on a smooth surface, like a cement sidewalk, release the propeller and the machine should rise and fly. If at first it is not successful try shifting the planes slightly forward or back or changing their inclination. Possibly you can reduce the weight of the machine. It is imperative to keep in mind while building the aeroplane that it

FIG. 43.—The aeroplane complete

must be exceedingly light in order to fly and that the parts must not be made any heavier than is absolutely necessary.

A still larger aeroplane with two propellers is made by making a triangular frame of $\frac{3}{8}$-inch square strips 42 inches long with a $10\frac{1}{2}$-inch strip of the same stuff for the base of the triangle. The apex of the triangle is in this case to be the front end of the plane and is provided with a pair of hooks to take the rubber bands, one set of which runs along under each long side of the propeller bearing at its hind end. The forward plane is small, about 12 by 4 inches, and is fastened in the plane of the triangle about 6 inches back of its tip, its longitudinal axis perpendicular to the altitude of the triangle. The rear plane is 36 by 5 inches and

attaches in a similar position 6 inches from the hind end of the triangular frame. This plane takes two 9-inch propellers. If the pull of the tightly twisted rubber bands tends to bend the long sides of the triangle, run fine wires one from the rear of each side to the apex of the triangle over a 2-inch upright of light stuff set on the middle of each side and bound in place. Skids may be provided as in the other plane, but they are not as necessary, for this plane is started off from the hands, each hand holding one propeller and letting go as the plane is launched by a shove out

FIG. 44.—Front view of a biplane built by seventh-grade pupils

from the shoulders as the person launching it stands upright. (See also Fig. 44.)

A very simple aeroplane propelled from a sling shot instead of by a propeller is made thus: Split a $\frac{1}{4}$-inch square wood strip, 10 inches long, at one end. Insert a light card $1\frac{1}{2}$ by 3 inches so that the ends of the card stick out equally on either side of the stick and its rear edge is $1\frac{1}{2}$ inches from the end of the stick. Bind it in place. Tack another card on the stick, the same size as this, its surface at right angles to the first, its rear edge at the end of the stick, its ends projecting equally from the sides of the

stick. Parallel to this card, at the other end of the stick, fasten one 8 by 1½ inches, its middle on the stick. Notch the stick under this near the end. Bend a piece of telephone wire in the form of a Y. Tie one end of a rubber band to the tip of each arm of the Y. Tie one end of a 6-inch string to the free end of one band, the other end to the other band. Hold the base of the Y in the left hand. Hold the aeroplane by the end near the small cards, between thumb and finger of the right hand, the string of the sling in the notch near the front end. Pull it back, stretching the rubbers, and release it for its flight.

CHAPTER IV

AIR AND WATER AS SERVANTS OF MAN

He that will use all winds must shift his sail.—FLETCHER

While the aeroplane has recently come into prominence as a means of aerial transportation, it was for a long time eclipsed by the balloon. The first balloon of which we have any record was manufactured by two Frenchmen, brothers, Jacques and Joseph Montgolfier. These men observed that clouds floated in the air, that the smoke from a fire which appeared very cloudlike rose into the air (see Fig. 61, p. 156), and they conceived the idea that if one could inclose a cloud or a cloudlike smoke in a thin bag, it might carry the bag up also. Their father was a paper manufacturer and so they could secure some large paper bags. They tried the experiment of inflating these with the smoke over a fire and found that they would rise. They then had a large bag made, some 30 feet in diameter, and proposed to make a public demonstration of their balloon. This occurred June 5, 1783, at Annonay, France. People came for miles around to this little village to see the spectacle, not knowing exactly what it was they were to see. The huge paper bag, reinforced with cotton fabric, was held by ropes over a smoldering fire of chopped straw. Gradually it was inflated, and when finally the restraining ropes were cast off, it sailed up into the air amid the cheers of the wildly enthusiastic crowd. The balloon rose rapidly until it was estimated to be a mile high; then, as the hot air in it cooled, it sank back to earth, having been up about ten minutes.

The fame of this marvelous event quickly spread through France. The king was desirous of having a demonstration, so that on September 19, of the same year at Versailles, the Montgolfier brothers sent up another balloon. This was still larger than the preceding one and oval in outline, the mouth of the balloon

being at the narrow end. A basket was attached to this balloon for the purpose of carrying passengers. No one, however, was bold enough to undertake the ascent, for it was not known at that time whether the upper air was fit to breathe, or in fact if there was any air up as high as the balloon might go. So the first three passengers to make a balloon ascent were a sheep, a rooster, and a duck. The ascent was eminently successful, the balloon sailed off some distance into the country, and came down in the field of a peasant. The peasant was thoroughly frightened by this visitation out of the skies, but the animal passengers were found to be none the worse for their experience.

On October 15, 1783, the first balloon ascension was made with a human being as passenger. The daring man to undertake this was a Frenchman, Pilatre de Rozier. In this first ascent it was deemed advisable to have the balloon attached to the ground by ropes so that it might not sail too high. De Rozier went up 100 feet, remaining in the air for some twenty-five minutes, and when he came down was enthusiastic over the delightful sensations of the ascent and the unobstructed view of the surrounding country that he obtained. In November of the same year this same man, together with the Marquis d'Arlandes, made the first free balloon flight. It was then looked upon as a foolhardy attempt. Their friends bade them goodbye as if they were going to certain death. The balloon used was again a hot-air balloon, and they ascended to a height of about 500 feet, remaining in the air about five minutes.

The difficulty with the hot-air balloon was that the air inside the bag cooled off rapidly. This of course could be overcome by carrying a basket below the balloon in which a fire could be built, and De Rozier, accompanied by the Marquis, made several ascents in a balloon of this type. The balloonists stood on the platform below the balloon and fed fuel into the fire which kept the air hot. They realized that this was risky since the balloon was constructed of paper covered with cloth and varnished to prevent the escape of hot air. They accordingly carried a bucket of

water and a sponge. On one of their voyages when they sailed across the city of Paris, the balloon repeatedly took fire, but they were fortunate in dashing the wet sponge on to the burning spots before the flames had done much damage. In this particular ascent they were in the air twenty-five minutes.

About this time (1784) Cavallo, in England, discovered what we now know as hydrogen gas, then called inflammable air. This gas is very much lighter than air, and Cavallo at once saw that it would be a good substance with which to fill a balloon. He tried to do this, but he could not get a bag that was sufficiently impervious to prevent the escape of the hydrogen. He did, however, blow soap bubbles with this gas, and they arose with celerity. Two French brothers by the name of Roberts and another Frenchman by the name of Charles did succeed that same year in building a balloon and inflating it with hydrogen gas. With such a balloon it was much easier to make prolonged ascents. In 1794 Monsieur Blanchard, accompanied by a Benedictine monk, made an ascent at Paris with a hydrogen balloon, reaching a height of 9,600 feet. In January the next year Blanchard and an American physician by the name of Jeffries undertook to cross the English Channel. They started from Dover and were slowly carried by the wind toward the French coast. It was only after they had thrown out all their ballast and much of their clothing in order to lighten the load that they reached shore safely not far from Calais.

The Frenchman, De Rozier, determined not to be outdone by any newcomer in the field of aeronautics, also undertook to make the trip across the Channel. To prevent his balloon settling into the sea as Blanchard's had so nearly done, he fastened below his hydrogen balloon a hot-air balloon with a fire-basket underneath it to keep the air hot. When out in mid-channel, at a height of 3,000 feet, his balloon was seen to burst into flames, an explosion followed, and De Rozier fell to his death.

The French military authorities were prompt to see the possibilities of the balloon in war time. In 1794 they used a captive

balloon as a means of observing the movements of the enemy, the Austrians. In this year Captain Coutelle, at the Battle of Mayence, went up 1,000 feet in a captive balloon which at that time was beyond the range of the Austrian guns. Here he sat and dropped written messages giving the French information regarding the position and movements of the Austrian troops. The Austrians protested this unfair method of waging war but the protests were in vain for the balloon came into universal use in military work. It was used frequently by the northern armies during the American Civil War, again at the Siege of Paris, 1871, and the British made use of it during the Boer War. During the Great War with Germany and her allies, the balloon was in constant use as an observation station. The old spherical balloon was early abandoned during this war for it was too unstable, bobbing around with every shift of wind. The Germans were the first to use the kite balloon, a long, sausage-shaped affair with a bag at the tail end. The mouth of this bag faced the wind so that it was blown full of air and served to steady the balloon as a tail steadies a kite (Fig. 45). The French kite balloon was an improvement on this, having three of these balloonettes at the hind end, one on each side and one below. Now practically all the armies of the world are supplied with observation balloons and the means of transporting them quickly by means of automobile and inflating them on the field wherever they are needed. The observer is in touch with headquarters

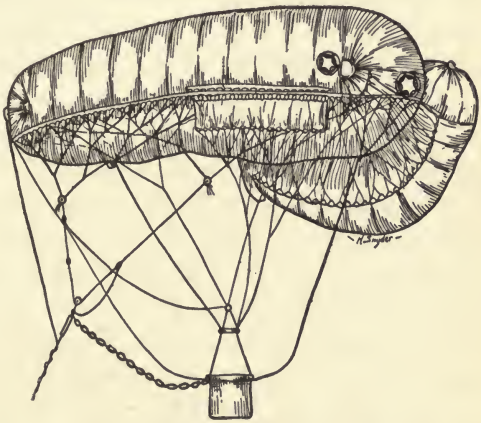


FIG. 45.—A military observation balloon

below by telephone, the wire of which runs down the cable by means of which the balloon is held. This cable winds on to a drum that is revolved by a small engine so the balloon may be brought down quickly if desired.

In all of the early balloon ascensions the balloonist was at the mercy of the winds, but early in the history of the balloon attempts were made to propel it. It was early suggested that a balloon might be equipped with sails and a rudder, as is a ship, but, of course, it was found that such a balloon, because it offered so large a surface to the wind, still drifted before the wind and could not get headway enough to steer. A French general by the name of Meusnier had a balloon made equipped with large cloth-covered oars and a rudder. The oars were torn away on the experimental flight by the winds, and the experiment was a failure as far as controlling the balloon was concerned. Meusnier's balloon, however, was an improvement in one respect—it was a long, cigar-shaped affair so built as to offer less resistance to the air. He suggested another improvement. One of the difficulties in the early balloons was that the gas would escape and the balloon would become shrunken and out of shape. He proposed putting a bag into the balloon which might be pumped full of air as the gas escaped and so maintain the shape. Another Frenchman by the name of Giffard was the first man to attempt to drive a dirigible by means of an engine. Giffard's engine, however, was not sufficiently powerful as it developed only three horse-power. His balloon was cigar-shaped, 144 feet long, 40 feet in diameter at its thickest point. When no wind was blowing he could drive the balloon at the rate of about 4 miles an hour. Experiments, however, continued to improve the balloon and its engine. Electric motors driven by storage batteries were substituted for the steam engine. It was not, however, until the gasoline engine was introduced as the motive power that real success came to the dirigible. The two men who are conspicuously connected with the success of the modern balloon are Santos-Dumont, a young Brazilian who was work-

ing in France, and Count von Zeppelin in Germany. Santos-Dumont made the flight from outside of Paris over the city, going around the Eiffel Tower. Zeppelin's dirigible was built on a somewhat different plan from that of the Frenchman's. In the German dirigible a rigid framework of light metal construction contained the numerous gas bags. The car and the motors were attached to this rigid framework. In the French balloons the gas bags were held in a net to which, below the balloon, there was attached the car for the aeronaut and engine. Later a long metal beam that hung below the gas bags held the car, thus making a semi-rigid balloon. The shape of the balloon was maintained by keeping the gas bags well inflated. These two types of dirigibles, rigid and non-rigid, are still maintained and, as is well known now, the dirigible was greatly developed during the war, although it did not accomplish what was anticipated, especially by Zeppelin, it would do in offensive warfare. However, the dirigible is now driven by sufficiently powerful engines to maintain headway even against a stiff wind. Such dirigibles have made long flights. In 1920, a British dirigible with both British and American men on board crossed the Atlantic from Ireland to America and returned. In 1923 the Zeppelin L-72, rechristened the "Dixmunde" by the French, its new owners, made a flight of 4,500 miles in a non-stop flight of 118 hours. There is keen competition between the dirigible and the aeroplane to see which will be more serviceable in the transportation of goods and passengers, with every prospect that both will serve, each in its particular field, in solving some of the difficult problems of transportation (Fig. 46).

It is an easy matter for the child to repeat some of the experiments that mark the discovery of the principles underlying the operation of the balloon. He may readily make the hot-air balloon, and directions for this are given in the *Field and Laboratory Guide in Physical Nature-Study*, page 49. He may make hydrogen gas and inflate soap bubbles as directed in the same book, page 54, and it is well for the child to go through such

experiments as a foundation for the comprehension of the science that is involved. Sooner or later he is bound to know why the balloon rises. The little child may be satisfied temporarily by some analogy to experiments with which he is more or less familiar. Thus you may tell him that just as a cork rises and floats on the surface of the water so the balloon tends to rise to the upper levels of the air. He may have had the actual sensation of being lifted off his feet when in swimming, and if he has learned

FIG. 46.—A dirigible balloon, the "Shenandoah," over New York Harbor

to float his experiences may lead him to some appreciation of the way in which a balloon rises, but in time he will persist in knowing more in detail the forces that are operative.

In order to understand why the balloon goes up, the child must have, as a rule, a number of new experiences that will clarify and render exact his hazy conceptions. The balloon rises because of the pressure of the air, and the child is neither familiar with gases nor with the law of pressure. When informed that the air is a gas he gains little notion of the characteristics of

gas, because the air and illuminating gas, which the term gas usually suggests, are both invisible and not readily handled in a way that leaves much impression on the mind of the child. Some experiments with such a visible gas as chlorine, for instance, is therefore worth while to render his conceptions more definite and exact. Directions for making chlorine gas are given in the *Field and Laboratory Guide in Physical Nature-Study*, page 54. It may be readily seen; it is heavier than air, therefore it may be poured from one bottle to another as water might be poured. Iodine gas may also be readily formed by heating crystals of iodine. This also is a colored gas and heavier than air. If the child can see some experiments of this sort he readily gains the notion that gases are somewhat similar in their properties and behavior to water, and he will more readily believe that the laws of fluids apply both to liquids and gases.

Some experiments can be readily performed to demonstrate air pressure. One of the classic experiments, historically, was an experiment performed at Magdeburg. Two large metal hemispheres were placed together so as to form a sphere, their edges being ground smooth so as to fit together quite perfectly. The air was then pumped out from the sphere, and when two horses pulling in opposite directions, one on each hemisphere, were unable to separate them, it was a striking demonstration of the pressure of the air on the outside of the two hemispheres. This apparatus is still known as the Magdeburg sphere and probably may be borrowed from the physics department together with an air pump to make the experiment for the children of the grades.

Light tin cans can now be obtained with a tin cover that presses into the opening of the can. Such cans are used in home-canning processes. They are also commonly used as containers of paint and molasses. Barely cover the bottom of such a can with water and then set the can on a stove or over a Bunsen burner and bring the water to a boil. The cover of the can may be laid on the opening but not forced on tightly. The can now

fills with steam driving out the air. When this happens, remove the can from the stove or flame and force the cover in tightly. As the can cools the water which was in the form of steam condenses and becomes water again. There was, of course, very little water in the can to start with, so that as condensation occurs the water occupies only a very small part of the space. Since the air was driven out by the steam there is little or no air in the can. The air pressure on the outside will crumple in the can.

Take a glass tube some 3 feet long and close one end of it by heating it in the flame. Directions for handling the glass tube in the flame are given in the *Field and Laboratory Guide in Physical Nature-Study*. When the tube has cooled, fill it with water, put the finger over the end and set the tube held in a vertical position, mouth down, in a bowl of water. When the mouth of the tube is under water remove the finger. Since there is no air in the tube above the water to exert its pressure on the column of water, the water in the tube is held up by the pressure of the air on the surface of the water in the bowl. If possible, repeat this experiment, using mercury in place of water. Mercury is much heavier than water so the air pressure will only support a column of mercury in the neighborhood of 30 inches high. The column of water supported in a similar way by air pressure is 33 feet high, for mercury is nearly fourteen times as heavy. This apparatus is the barometer and as the height of the mercury varies it shows the variations in the pressure of the air. At sea-level normal pressure is about 30 inches; but this may vary considerably, dropping as the pressure decreases or rising as the pressure increases. A barometer is a very useful instrument to indicate sudden changes of atmospheric pressure that herald the approach of storms.

Such experiments will help the child to appreciate the fact that air has pressure. When we say that air has pressure we simply mean that air has weight. We may demonstrate the fact that air has weight in another way. On a pair of scales lay a football that is distended but not blown entirely full and bal-

ance it exactly by weights in the other pan. Now blow up the football, forcing just as much air into it as you can. Put it on the scale pan again and you will notice that it is slightly heavier, due, of course, to the added air that has been forced into it.

Next we need to demonstrate that the pressure of a fluid is exerted equally in all directions. A tin can with glass tubes set into its top, sides, and bottom and filled with water will show that the water stands at the same level in all the tubes (Fig. 47). See the *Field and Laboratory Guide in Physical Nature-Study*, page 51. Pressure, therefore, of the water must be exerted in all directions in order to maintain the columns of water in all of these tubes. The pressure in the tube let into the bottom of the can must be downward at the end of the tube that projects into the can. It must be likewise sideways at the ends of the tubes inserted into the sides of the can. Another simple device for showing that the pressure in the water is equal in all directions is made as follows: Tie a piece of sheet rubber tightly over the mouth of a thistle tube. Cut off the stem of the thistle tube (see directions for cutting glass in the *Field and Laboratory Guide*, p. 50) about 1 inch from the bulb of the tube. Slip a 3-foot piece of rubber tubing on to the short stem of the thistle tube. Draw out the cut-off stem of the thistle tube at about its middle point so as to make a fine glass tube. Break this at the middle point and put one of the pieces into the other end of the rubber tubing, the fine end out. Press lightly on the stretched rubber over the mouth of the thistle tube, insert the fine end of the glass tube into red ink, and slowly release the pressure. The red ink is drawn up now into the fine end of the tube. By rubber bands fasten this glass tube on to a ruler or meter stick. Now stick the thistle tube down into a larger beaker of water. As the thistle tube goes down notice that the red ink moves in the tube.

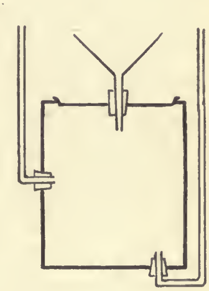


FIG. 47.—Diagram of can with tubes in it to show water pressure.

The increasing pressure of the water drives in the rubber diaphragm, exerts pressure on the air in the apparatus which forces the red ink to move. Note the depth to which the thistle tube has been sunk and also the position of the red ink against the scale. Now place the diaphragm of the thistle tube at the same depth in the water but turned up instead of down and note the pressure. Let it be turned sideways at the same depth. In all these positions the drop of red ink in the small tube will register the same on the scale, showing that the pressure of the liquid is the same in all directions.

Having given the child now some notion of the nature of gas and an appreciation of fluid pressure and the fact that the pressure is exerted equally in all directions, we must next give some conception of what happens when a body is immersed in a fluid. Cut from a block of plasticine a piece 1 centimeter wide, 1 centimeter thick, and 5 centimeters long. Cut this as accurately as possible. Fasten a piece of thread to this so that it may be lowered into a glass graduate of 100 cubic centimeters capacity. Fill the graduate up to the 50 cubic-centimeter mark with water and then lower into this the piece of plasticine. The water in the graduate will now rise to the 55 cubic-centimeter point, and, since the block of plasticine contained 5 cubic centimeters, it is evident that a body immersed in water displaces its own volume of water. Withdraw the block of plasticine and press it out of its regular shape between the fingers, then lower it again into the water. We still, of course, have 5 cubic centimeters of plasticine in the block, and it will still displace the same volume of water, but now the child knows that this law holds true even with irregular objects.

The history of the discovery of this law is interesting. A certain king of Greece had given to his artificers of metal a lump of gold which was to be made into a crown. The king suspected that his workmen had abstracted some of the gold and that the crown was made in part of silver—a much less valuable metal—which had been substituted for the gold by his craftsmen. He

called in the Greek scientist, Archimedes, and assigned him the task of determining whether the crown was pure gold. The king required that he solve the problem within a specified time or lose his life. Archimedes, therefore, went to the task with much energy. He knew, of course, that gold is much heavier than silver, and if he could but know the volume of the crown, knowing the weight of gold, he could tell how much it should weigh. His chief problem, therefore, was to find the volume of the crown. He could not, of course, pound it into a lump that could be measured, and so he pondered intently on the task of measuring the volume of the crown. The story relates that he went to take his bath and rather absent-mindedly filled the tub too full, and when he got into the tub the water overflowed. Archimedes saw at once that a body that is immersed in water displaces its own volume and herein was the means of determining the volume of the crown. He was so excited that he ran home from the bath, crying, "Eureka! Eureka! I have found it!" much to the astonishment of the citizens, for he had not waited to put on his clothes.

Now cut out another block of plasticine the same size as the one used above, and weigh it carefully. Again fasten it to the thread and fasten the thread to the pan of the scales or the hook of a spring scale. Immerse the plasticine in water as before and note what it weighs as it hangs in the water. Remove the plasticine and exactly balance a glass graduate on the scales, then add 5 cubic centimeters of water. It will be found that the water weighs 5 grams and also that the difference in the weight of the plasticine in air and in water is 5 grams. In other words, the plasticine immersed in water loses as much weight as the weight of the water which it displaces.

The reason for this is perfectly evident when we consider the block of plasticine immersed vertically in the water. The pressure on opposite sides of the block will evidently be identical since the opposite sides are exactly of the same area and are at the same depth in the water. The downward pressure on the

top of the block as far as the water is concerned is evidently equal to the weight of a column of water 1 centimeter square and as high as the distance from the top of the block to the surface of the water. The upward pressure of the water on the underside of the block is equal to the weight of a column of water 1 centimeter square and as tall as the distance from the underside of the block to the surface of the water. The upward pressure on the underside of the block, therefore, exceeds the downward pressure on the top of the block by the weight of 5 cubic centimeters of water, which, as we have seen, is 5 grams.

If now the immersed object weighed less than 5 grams, the pressure on the underside of the block would evidently force it up to the surface, and it would rise out of the water until the portion of it in the water displaced a volume of water equal in weight to the weight of the object. If you float a cube of cork on water, and mark the line at which the surface of the water stands on the cork, then cut the cork in two along this line, you will find that the weight of the cork is the same as the weight of a volume of water equal to the part of the cork that was below the water-level.

It is now easy to see why a soap bubble filled with hydrogen gas, which is lighter than air, rises, but one more thing must be explained before the rise of the hot-air balloon is clear, that is, that heat expands things. Unscrew a nut from a bolt and heat the screw end of the bolt until it is real hot. Now try to put the nut on. It is evident that the end of the bolt has enlarged, expanding in the process of heating. Fill a small flask one-third full of water to which a little red ink has been added to color it. Bore a hole in a cork that will fit the flask and insert in this hole tightly a small glass tube, so that when the cork is in the flask the end of the tube will dip into the water. Insert the cork in the flask tightly. The colored fluid will rise part way up the tube. Now hold the flask in your warm hand and watch the level of the water in the tube. It is very evident from this experiment that the air in the flask as it warms expands and forces the water higher up the tube.

When the hot-air balloon is held over a fire the heat expands the air within the balloon and some of this air must therefore escape out of the bottom of the balloon. Since there is less air now in the balloon than there was to start with, the volume of air in the balloon weighs less than the same volume of air outside of the balloon, and therefore the balloon will rise if this difference is greater than the weight of the balloon.

The principles which have just been explained and illustrated are the ones on which depend the floating of a boat. It seems strange at first thought that a boat may be constructed entirely out of iron and steel, substances which will themselves sink promptly in water, and yet the boat built of them will not only float but will carry a great load of freight. The explanation is, of course, perfectly simple. The boat is not solid steel but is a hollow affair. When it is put into the water it settles down until the weight of the water which it displaces is equal to its own weight. As you load the boat it settles deeper and deeper, displacing an amount of water equal in weight to the weight of the load added. If you continue to load it, it settles until finally the edge of the boat is flush with the water. Then, added load will sink it. All of this may be experimentally verified with a thin glass vessel or a tin pan floated on water and loaded with weights. You may mark the level of the water on the vessel and get the weight of the water it would contain up to that mark. There will be a slight discrepancy between the weight of the contained water and the weight of the vessel and its load, for the contained water measures the volume of the inside of the vessel while the water is displaced by the outside of it. If the glass vessel is very thin this discrepancy will be very slight.

When the wind hits the sail of a vessel the force with which it strikes is resolved into two factors and one of these serves to drive the boat forward. In a similar way it will be recalled (p. 80) that the force of the wind is broken into two factors as it strikes the kite and one element lifts the kite into the air. If the boat is running before the wind then its sails are set at right

angles to the axis of the boat so as to catch the full force. Still it can go no faster than the wind is blowing for the sails would then act as drags and hold it back. But in a good breeze a boat with its sail set at an angle to the wind (frontispiece) may go faster than the wind is blowing for the factor that shoves the boat ahead may be much greater than the resistance the water and air offer to the hull and superstructure of the boat.

This art of sailing a boat with the sails set so the wind strikes them at an angle is a fairly recent innovation. In old times the sailboat simply ran before the wind. It was not until 1537 that Fletcher, an Englishman of Rye, discovered it was possible by proper adjustment of sails and rudder to sail a boat into the wind—a discovery of great importance commercially, for ships now sail to their destination even with a head wind. The discovery was of great importance historically, too. When the great Spanish "Armada" set sail to conquer England the ships were of the old type—high out of the water to catch all possible wind. They were able only to run before the wind in the storm that struck them. The English boats were low-lying vessels that could sail into the wind and could easily gain positions to rake the Spaniards with their broadside of cannon fire and get away before the Spanish gunners could return it. Between the storm and the new type of sailing vessel that had come out of Fletcher's discovery, with the new skill in handling such craft, the course of events in history was turned quite unexpectedly.

In the twenty-five years or so prior to our Civil War no sailing craft in the world were as famous for speed as our American Clippers. The American merchantmen were then the world's greatest carriers, and our foreign carrying trade was exceeded by no other nation. The "Flying Cloud" in a trip from New York to San Francisco ran 1,256 miles in four days. The "Sovereign of the Seas" in one day's run sailed 411 miles while the "Lightning," record-maker, sailed 436 miles in one day. These are good records even for steamers.

When the boat is driven by a propeller the force with which the propeller blades strike the water is decomposed, one element serving to drive the boat ahead just as the propeller of the aeroplane carries it through the air (p. 99). At present the record for speed boats is held by "Miss America II." Her official record is 80.56 miles per hour, made in 1921. Nothing like this speed is maintained in commercial craft. Still the best of the transatlantic liners now make 23 to 25 knots per hour, and the latest battleships make 35, while destroyers run at still higher speeds.

We do not know at all who first devised the boat, and we can only guess the steps by which its discovery progressed. Still the very primitive types of boats yet in use help us to formulate guesses that are probably nearly correct. As far back as history goes sailboats were used and these, quite pretentious ones. On an old vase, now in the British Museum, which was found in an Egyptian tomb is the relief of a sailboat. This boat was also manned by many oarsmen, for on the Nile wind is not always a dependable motor power. This vase is one of the oldest relics of ancient Egyptian civilization that has come to light, probably 3,000 years old or more. In the oldest code of laws yet discovered, laws written on the clay tablets of the ancient peoples in the Tigris and Euphrates valleys, there were strict regulations in regard to the course of vessels and their movements when passing each other or in coming to port. Marble models of boats from this same time, probably votive offerings, show their general shape and structure, the holes for the masts and the rigging being visible still, though masts and shrouds are gone to dust.

Probably boats have been devised and used independently by various peoples in different parts of the world, and we shall never know exactly by whom the various types of primitive craft have been invented. One can readily imagine, however, how the savage, desirous of crossing a stream, straddled a floating log and trusted to the current or the wind to land him on the other shore. He must soon have found that his arrival at his destina-

tion was rendered more certain by poling his way across. Boats, or rather rafts, consisting of a few light logs or poles fastened together with thongs or ropes of grass, are still to be found in China, Japan, and other countries where the light bamboo makes ideal material for such craft. One wonders how many centuries it was before the primitive boatmen learned to use the pole as a paddle when they worked out into deep water. Then some inventive genius fashioned a paddle more skilfully, widening its blade, and so contributed to the advance of mankind. Then it is to be presumed some tribes living along shore, instead of trusting to luck to find a suitable log when needed, pulled up the logs, once used, on shore to be used repeatedly. One can readily conceive how some fellow, brighter than the rest, chipped off with his stone hatchet a place to sit, so as to make his log more secure and more comfortable. In time the log was all flattened, for standing on a slippery rounded log is precarious business. Finally the log was dug out so as to hold the fish, the products of the chase, or the boatman's belongings when he went on long expeditions.

Such dugouts are still widely used and are no mean boats. A huge log is shaped by the patient labor of many workers toiling with crude tools. It may be chipped out or hollowed by fire. Such a craft may hold thirty or forty warriors. These war canoes are used by the people of Africa, South America, Asia, and by the South Sea Islanders. The latter tribes have increased the stability of the canoe by fastening long, light logs out at each side by means of poles. These outriggers prevent the canoe from capsizing and make it quite seaworthy.

Possibly the next step in advance was taken when it occurred to some early man that he might save labor by fashioning a framework of light sticks and covering it with skin or bark, thus avoiding the task of cutting out the hard heartwood of the log. Perhaps such canoes were made first in a region where timber was scarce. At any rate, boats of this type are still familiar, such as the birch-bark canoe of the American Indian, the skin-covered

kyaks of the Eskimos, and the curious basket-like coracles of the Welsh (Fig. 48).

Probably very early in his primitive life man discovered the value and use of some of the simpler machines such as the lever and the wedge. Much later, he devised the more complex contrivances to aid him in his tasks. The windmill and the water wheel are among the earliest of them to appear.

The windmill is a rimless wheel the spokes of which are flat or slightly curved blades set at an acute angle to the plane of the wheel. The principle of operation is simple. When particles of air moving along the surface of the earth as a wind strike these blades, the mill headed into the wind, the force of the blows is resolved into two components, just as in the case of the kite (p. 80), and one of these component forces turns the mill around. A crank arm attached to the axle of the wheel which turns with the wheel transmits the power to the pump or other machine to be operated by the mill.

FIG. 48.—A coracle

To make the paper windmill, take a 6-inch square of paper, preferably colored paper. If the paper is not already cut in such form, proceed as follows to cut a 6-inch square out of any rectangular sheet of larger size. From any corner of the sheet measure 6 inches along each adjacent side, and mark the points. Fold the corner over and crease the paper along the line connecting the marked points. With the scissors, cut the paper close to the folded-over edges.

Draw lines on the 6-inch square, running from each of two adjacent corners to the diagonally opposite corners. Cut in

from the corners along these lines to within a half-inch of the intersecting lines. Lay the left hand, back down, on the paper, the fingers about at the center. With the right hand fold in any one corner and hold it with thumb and finger of the left hand. In the same way fold in every alternate corner around the square, and when all are in hand run a pin through the four infolded corners and also through the center of the square. Thrust this pin into a wood handle and the windmill is complete.

An eight-point windmill may be made in place of the four-point, as follows: It makes the mill more attractive if paper of two colors is used. Cut a 6-inch square of paper of each color, and cut in from the corners as before. On one paper make a half-inch cut at the inner end of each diagonal cut on the left-hand blades, making it at right angles to the edge. Lay this square upon the table, the second square upon it so that the centers coincide and so that the corners of the upper sheet are midway between the corners of the lower sheet. Then insert each alternate edge of the upper blades into the cuts on the lower blades. Then fold over all the inner points as before and run the pin through them and through the centers of the two sheets. Stick the pin into a handle.

To make the wooden windmill, cut two 8-inch lengths of wood $\frac{7}{8}$ inch square. Find the middle of each piece and mark a cross-line at this point. Draw two lines parallel to this, one at each side of it, $\frac{7}{16}$ inch distant from it. Saw into the strip on each of these two lines, cutting halfway through the strip. Cut out the central block. The two strips may now be put together at right angles to each other, the space formed by cutting out the block fitting over the remaining section of the other stick. See that they fit well.

With a knife shave off the opposite angles of one arm until a thin blade of wood is left. The central region is not cut away, but bevels on the thin blade. Cut each of the other arms in the same way, so that the blades are inclined in the same direction. Fasten the mill thus formed securely to a cylindrical stick somewhat larger than a pencil.

The base of the windmill is built thus: Cut a 3-inch length of $\frac{1}{2}$-inch stuff that is 1 inch wide. At each end with small brads fasten on a 2-inch length of the same material at right angles to the 3-inch strip, the two shorter strips parallel to each other and on the same side of the 3-inch strip. Bore a hole near the top of each 2-inch piece, the holes in line so that the cylindrical piece fastened to the windmill may be run through them. Bore a hole in the middle of the 3-inch piece. This is fastened to the upright piece, which should be $\frac{7}{8}$ inch square and 8 inches long. Cut a thin piece of wood out of a cigar box or similar material to form the vane of the mill. Let this be 6 inches long and 4 inches wide, with a projecting piece sticking out from the 4-inch side, the projection to be 1 inch long and $\frac{1}{2}$ inch wide. Tack this projection to the 3-inch strip that makes the base of the structure that carries the mill so that the vane projects from the base in a vertical plane parallel to the cylindrical strip that serves as the axle for the mill.

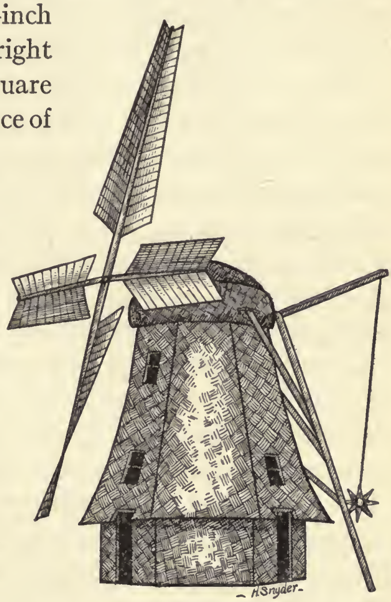


FIG. 49.—An old-fashioned windmill

When this vane is on the basal strip, fasten the base to the upright support by running a flat-headed wire nail through the hole bored in the basal piece; drive it in through the center of the end of the supporting upright. Put the axle of the mill through the holes bored in the supports and drive a couple of small brads through the axle, one on either side of one of the supports, so that the mill will be held in place.

The blades of the old-type windmills were wooden frames covered with cloth and were often spoken of as the sails (Fig. 49).

The mill usually bore four sails. In the modern mill the blades are smaller, more numerous, and made of wood or steel.

In many parts of the Old World as well as in America the country landscape is dotted with such mills raised into the breeze on towers. They furnish the farmer with power for pumping water, for running his electric plant, his churn, and many other small farm machines. They have been used, too, for power to grind his grain. When not in use the mill is turned with the edge of the wheel into the wind instead of its face. This is easily accomplished with the modern, small, light mill but it was not so easy a task with the old mill with its great expanse of sails. Sometimes the sails were furled as on a ship. Again a great slanting beam was attached at one end to the axle of the mill while the other end rested on the ground or was attached to a wheel on the ground. Then horses or oxen could be attached to this end so the mill could be turned on a pivot into the desired direction. Another scheme was to have the tower or perhaps merely its top rotate on its axis and turn by means of a rack and pinion that could be operated by a great hand crank.

The early water wheel was a paddle wheel. The blades were wide, usually four in number, and radiated from the hub with their faces set at right angles to the plane of the wheel. Such a mill wheel might be set so its blades dipped one after another into a stream of water that ran under it, the undershot wheel, or the water coming from some source above the wheel was led by a trough or flume so it fell on the tip of the blade, first one, then another, as the wheel was made to revolve by the falling water, the overshot wheel.

Now, however, it is much more customary to set a wheel like a windmill at the bottom of a vertical pipe through which water is flowing from some height when the wheel is turned by the passing water just as the windmill is turned by the passing air. Such a wheel is known as a turbine. We have seen (p. 112) that water in a vessel exerts a pressure of about 15 pounds per square inch for every 33 feet of height of the water. So that if the

column of water in the pipe is several times 33 feet the force exerted on the blades of the turbine is as many times 15 pounds to the square inch. This force is resolved into two factors, one of which pushes the wheel around. Such a turbine wheel set at the bottom of a waterfall with water filling the pipe as it flows into its upper end at the top of the falls may develop a tremendous horse-power. So they are using a part of the water at Niagara Falls to develop power for manufacturing plants. Every stream with a rapid current may be dammed, and the falling water be used in a similar way (Fig. 50, p. 126). In Switzerland the railroads are to be run entirely by electricity developed by power plants that are to be operated by such means. The work of installing the necessary turbines and power stations is proceeding rapidly, and some sections of the lines are now operated by electric locomotives. The Lake Ritom power-house receives the water from a source far above the station. It is led in through cement conduits and has a head of 2,580 feet, so giving a pressure at the turbines of 1,150 pounds per square inch. Six turbines are installed that yield 70,000 horse-power.

Some of our own transcontinental lines are using electric locomotives in the mountain sections, the power being furnished by hydroelectric plants, and are finding that they can haul the trains more rapidly and more economically. About 20 per cent of the freight-hauling capacity of our railroads is now used in distributing the fuel needed to supply their engines, while another 10 per cent is used in hauling the coal in the engine tenders. Electrification would save this wastage.

The utilization of our water power—white coal, it has been aptly termed—will relieve greatly the demand made now on our fuel supply. It is estimated by the United States Department of the Interior that we have in this country an available water supply of 60,000,000 horse-power, and that of this we are now using some 10,000,000 horse-power, thus saving annually about 33,000,000 tons of coal. Some of the states are very fortunate in possessing many streams with precipitous descents—notably

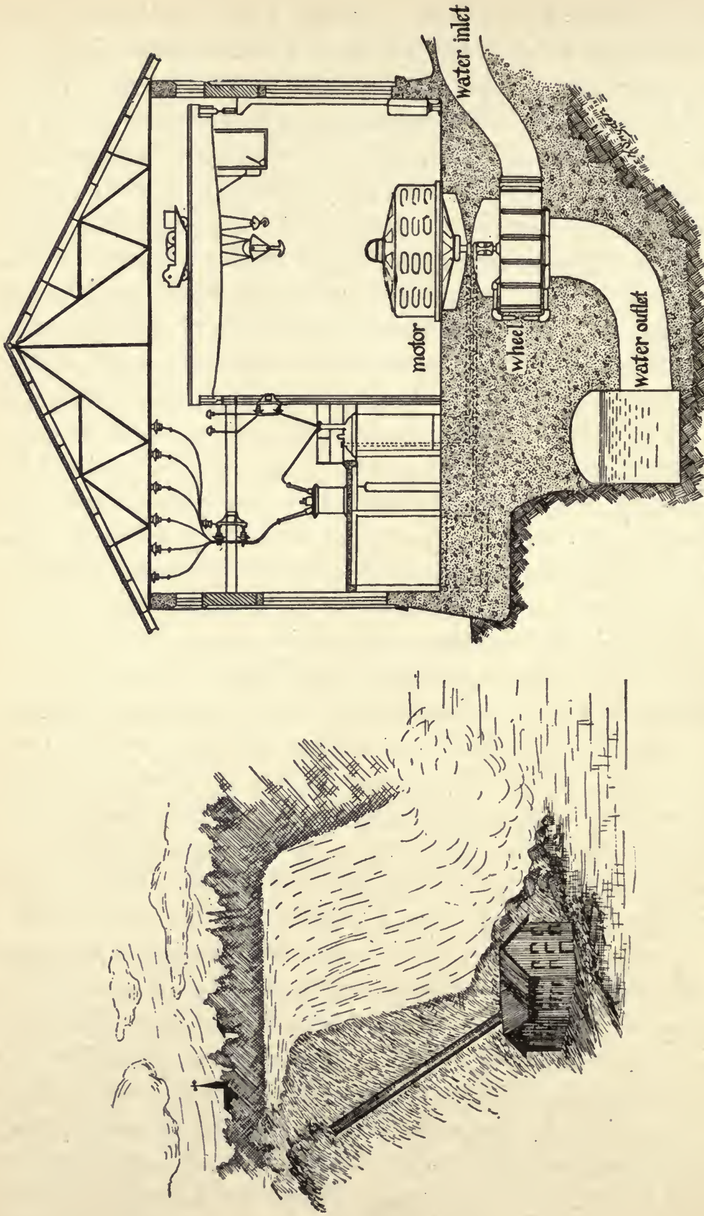


Fig. 50.—Location of a water-power plant and cross-section showing plan

the mountain states—from which they may develop immense power for factory purposes. Vermont is already using its water power nearly to the limit; Illinois is using about 50 per cent of that which is available; Washington, about 5 per cent.

One of our great national problems is the careful development of this power so that the rights to its use may not fall into the hands of private interests without ample compensation to the people of the states and nation for its use. Timber lands, coal lands, and mineral lands belonging to the people as a whole have been sold to private concerns and to individuals for a mere pittance, and these lands have yielded millions of dollars to such private interests with no return to state or nation other than the meager purchase price. Thus the iron and copper lands of northern Michigan were sold in many cases for $1.25 an acre. One mine, the Calumet and Hecla, yielded over $13,000,000 worth of copper to enrich its owners. Thousands of acres of government land on which stand the great western forests, the finest in the world, have similarly been sold when the lumber from a single tree will pay the purchase price many times over. One of the great redwoods yields enough lumber to build several bungalows. It remains to be seen whether we as a people will part with our water power in the same careless manner.

Another device that has been of inestimable value to man is the pump. It, too, depends on these principles of fluid pressure, although it was in use long before the principle of its operation was understood. Both lift pump and force pump may be readily constructed and the method of operation will be better understood after they have been made and operated.

The lift pump is made readily as follows: Take a length of good-sized glass tubing 12 inches long, a paraffined mailing-tube, or a piece of bamboo. Cut a piece of wood 15 inches long and about as large around as a lead pencil, for the plunger handle. At one end of this fit a slice of cork for a plunger and fasten it securely. The cork should fit the tube snugly. Punch

a hole through the cork and then with a small tack fasten a flap of leather so that it will cover the hole on the handle side, the tack being placed at one side of the hole. The cork should be free to slip up and down rather tightly in the tube when worked by the lift handle. Put a cork in the lower end of the tube, having first made a hole in it, and cover the hole with a leather flap held by a tack, the flap being on the inner face of the cork. Put this corked end of the tube in the water and work the plunger back and forth. If properly constructed, the water rises in the tube and is pumped out at the top. A tube made of rolled paper may be set with glue in the mailing tube or bamboo, to serve as a spout.

To make a squirt gun fit a cork into one end of a good-sized glass tube or length of bamboo, but before inserting it file or cut a groove on one side. Make a plunger, as was done for the pump, except that there will be no valve in this. Put the head of the plunger into the free end of the tube or length of bamboo, drive it down nearly to the cork, put the corked end under water, draw the plunger back slowly, lift the corked end above the water, and drive the plunger rapidly down. This squirt gun illustrates the principle of the force pump.

As the stream of water comes from the force pump of the waterworks into the faucets in the house, or from the hose nozzle connected to the fire engine, the stream is a steady stream and not a succession of spurts. This change is brought about by the addition of an air chamber, which has an inlet and an outlet. The water coming in, in a succession of spurts, crowds up against the cushion of elastic air, the pressure of which sends the water out in a steady stream. Replace the cork in the squirt gun with one having two holes, one for intake, one for outlet. Put short lengths of glass tubing in each so that the ends are flush with the small end of the cork. Attach a leather valve over the intake tube so that it will let water in but not out. Attach a rubber tube to the intake pipe and let its free end set in a glass of water. Fit a cork with two holes into a 4-ounce wide-mouthed bottle.

Put lengths of glass tubing into the cork, the end of one flush with the inner end of the cork, the end of the other reaching nearly the bottom of the bottle. Put a valve over the end that is flush with the cork so that it will let water in. Connect this one by a short length of rubber tubing to the outlet of the squirt gun, now to be used as a force pump. Connect a short rubber tube to the outlet of the small bottle and put a pipette glass into the other end of this rubber tube. Then operate the pump and a steady stream will issue from the pipette "nozzle."

When the handle of the ordinary pump is brought up (see Fig. 51) the plunger is forced down in the cylinder, the air escaping through the valve in it. When the handle is forced down the plunger rises, the valve closes at once, and so a vacuum tends to form under the plunger. The pressure of the air on the surface of the water forces the water part way up the pipe. The valve in the bottom of the pipe lets the water in but prevents its escape as the plunger descends again. This process is repeated until the water rises to the plunger, when it flows through the valve opening as the plunger is forced down. The water is then raised above the plunger until it flows out of the spout. If the plunger and valve get dry so they leak air, they must be made air-tight by "priming" the pump, pouring water into the pump from above. Such a pump cannot work when the distance from the plunger to the surface of the water in the well is over 33 feet.

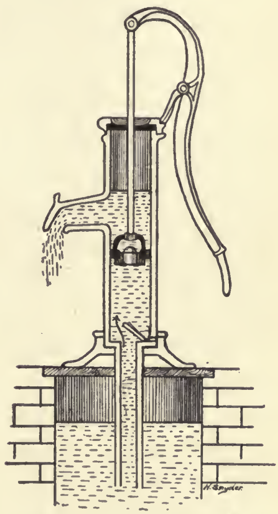


FIG. 51.—Diagram of a lift pump.

CHAPTER V

THE SLING, BOW, AND OTHER WEAPONS

Fight, gentlemen of England! fight, bold yeomen!
Draw, archers, draw your arrows to the head!

—SHAKESPEARE, *Richard III.*

We think of this modern age as the age of great inventions, and justly so, for more inventions of major importance to civilization have been made in the last hundred years than in any like period. The aeroplane, automobile, gas engine, telephone, telegraph, locomotive, steamboat, harvester, spinning jenny, and many others occur to one on a moment's reflection, all belonging to the years since 1800. And yet we must not forget that our very early forebears also made great discoveries and that we are indebted to them for many of the most important inventions that are fundamental to our activities. They discovered how to produce and use tools, weapons, language, fire, how to plant and cultivate crops, how to domesticate animals, how to cook food, build houses, make clothing. Should not that savage who first conceived and put into practice the idea of planting seeds where he wanted them to grow instead of searching for his grains and fruits where they had planted themselves, or that one who first cultivated his garden patch with a sharp stick, be accorded quite as great glory as he who perfected the harvester? I wonder what savage first used a sharp-edged flake of flint to cut the meat from the dead beast instead of tearing it off with fingers or teeth, who first used a stone as a hammer, or first found he could hurl a stone and kill his quarry. Such primitive tools and weapons are a far cry from our modern machine tools and engines of destruction, yet they were prime discoveries, and since their invention we have merely improved them.

I suppose the first weapon was a club that the savage discovered increased the reach of his arm and force of his blow, or possibly it was a stone held in his hand to add to the power of his punch. Then he learned to throw the stone or hurl his club as a crude spear. Finally, he discovered how to shape his spear to make it more effective, how to make devices that would hurl the stone or spear farther than he could unaided, and so came the sling, bow, blowgun, and other similar appliances.

Such progress as is here briefly sketched in few words took long ages to accomplish. Man has come up very slowly from a savagery that was next door to animal existence. For tens of thousands of years his language was made up of grunts and gestures. He built no shelter, made no clothes, had no tools, no weapons, ate raw foods, since he had not learned the use of fire, and trusted largely to chance for them, eating only as luck gave him a meal. In fact, his existence was a bestial one with merely a shade of advantage over his animal competitors because of his increased cunning. This is not merely guesswork, for we have discovered the skeletons of these early men in caves where their bones, together with the bones of some of the animals that lived there, have been covered up and preserved by deposits of lime or accumulated clay. There are no vestiges of tools, weapons, utensils, no evidence of fire or clothing, as are found in similar situations among the remains of the men of later ages.

One of the very early weapons of mankind was the sling. Every child is familiar with the story of David and Goliath and will recall that it was with the sling that David killed Goliath. This sling is made out of a piece of leather large enough to hold the stone that is to be thrown. A leather thong or string some 30 inches in length is tied on each side of the leather; the free ends of the strings are held in the hand, one firmly, the other so it can be readily released. The sling with the contained stone is then swung round the head and, when the stone is swinging with great rapidity, the thong is released and the stone flies out of the sling. The boy who undertakes to use this sling for the

first time should go well away from buildings and companions, for at first the stone is likely to be thrown in a direction quite different from that intended, and it requires much practice to become skilful in hitting a mark.

This simple weapon is illustrative of several important scientific principles. Primitive man, of course, did not comprehend these. In fact, we usually acquire control over the forces of nature by a trial-and-error method. We learn first how to do things and later inquire why things behave as they do. It is always interesting, however, when we can understand the reason why. When any object is at rest it requires the application of force to move it from this position of rest, and when a thing is in motion it tends to continue that motion in a straight line unless something acts upon it to stop it or start it moving along another line. This is called the law of inertia. When the stone is swinging rapidly around in the sling and one thong is released the stone moves in a straight line in the direction that it was going at the moment of release, and it keeps on going until it is stopped by striking some object. If no other object is struck it is, of course, striking particles of air all the time and gradually these check its movement and it drops to earth pulled down by the earth's attraction, what we call the force of gravity. The stone is held in the sling because every moment it tends to fly off in a straight line, and so presses against the leather which restrains it. Probably most children have amused themselves by taking a small pail partly full of water and holding the handle of the pail in the hand have swung this around in a vertical circle. Of course, when the pail is directly overhead with its mouth down, the water would spill out of the pail if the pail were not being swung rapidly. Because of the inertia the water tends to fly away from the center of the circle in which the pail is being swung and therefore presses against the bottom and sides of the pail, so remaining in the pail, a demonstration of the so-called centrifugal force. This experiment will help one understand why the stone stays in the sling when it is merely laid in the leather and not fastened to it.

It is this centrifugal force that causes a flywheel or rapidly revolving grindstone to break and fly in pieces, sometimes doing much damage. This same force is used in the cream separator and the centrifugal laundry wringer. In the latter the clothes are put in a rotating drum with perforated sides, out of which the water is thrown as the drum whirls. In the cream separator, water, casein, and other heavy parts of the milk are thrown out from the rapidly rotating bowl while the light cream remains at the center.

The common top is an admirable illustration of this same law of inertia. When the top is set spinning each particle of it travels in its own path and resists any force that acts to move it out of that path, so that while it would not for a moment stand straight up on its peg if it were not spinning but would promptly topple over, when it is set going it resists the pull of gravity and stands erect as it spins. When the top is spinning on your hand you may incline your hand but the top remains upright. The skilful lad even lets the top spin down a string stretched from hand to hand, one end lower than the other, and the top maintains a fixed inclination as it slides along instead of falling off, for its inertia resists the pull of the earth.

A passenger boat is just being put on the route from New York to England that has in its hold a great metal disk weighing 100 tons that is set on an axle in a frame so it may be rotated with great speed. It is expected that this great rotating disk will resist the force of the waves that makes a ship roll and keep it steady, a gyroscope stabilizer. If the device is as successful as its designer expects, many passengers will be delighted to have the good ship spin its top all the way over.

The bow and arrow are very old weapons. Crude, chipped-stone arrowheads are found very deep in piled-up strata of soil, clays, sand, and gravel that must have taken many thousands of years to accumulate. In the same beds in which the arrowheads are found, there have been discovered in Europe parts of the skeletons of very primitive men and of ancient animals that man

then hunted but which are no longer living in Europe, such as the straight-tusk elephant, the mammoth, the hippopotamus, the giant beaver, bison, and the lion. The wounds made by the hunters' stone-tipped arrows are still discernible in some of the bones of the well-preserved animal skeletons. Just how old these early arrowheads are, there is difference of opinion, but probably they were made by primitive man well over 100,000 years ago. There are still savage tribes who hunt with the bow and arrow, so that it is a weapon that has been used by man these many hundreds of centuries.

The bow and arrow are largely confined to those savage peoples inhabiting regions where some very elastic wood grows. It is essentially an arm of the natives of North America and Asia. In the latter territory the bamboo is used chiefly in its construction; in North America, however, a great variety of woods enter into its construction. The Indians of California used the desert juniper; the plains Indians, the osage orange, called by the French *Bois d'Arc*, or bow wood. In many cases the bow was backed with deer sinew glued on and strengthened by encircling bands of sinew along the bow. Among the Eskimos the sinew furnishes the elasticity entirely, the wood being applied in small bits for the sake of rigidity, for it is scarce.

The bow has played no mean part in the history of the civilized world. Apart from its service in obtaining food and clothing for man by bringing down the quarry for the huntsman, it has been the deciding factor in many a hard-fought battle. The armies of the ancient peoples, the Babylonians, Egyptians, Greeks, and Romans, all have had bodies of trained archers. The Hebrews found some of their foes so well trained in the use of the bow that they were compelled to adopt it, also, and train their archers.

It was not until the long bow was perfected by the Scotch and English that the bowmen came to be really formidable. This long bow was 6 feet or more in length, was made of stout yew or lance wood, and drove a feathered arrow 30 inches in length with such tremendous force that it would go entirely through

a deer at 300 yards. The Indian buffalo hunter often drove his arrow through the huge beast, firing from horseback as he rode beside the herd. In such famous battles as Crécy and Agincourt, the lance, sword, and bow were the weapons in use, but the last was the most important. So thickly did the arrows fly that armored knights were in a perfect storm of them, and woe betide the warrior whose armor offered the slightest opening for the expert bowman.

The manufacture of the bow and arrow was a craft by itself. The weapons needed to be made with as much nicety and as much care in the selection of the material as the modern firearm. The bow was usually made of several strips of wood glued together and not infrequently was made in parts, a central portion and end pieces. Sometimes several different kinds of wood entered into the composition of the bow, but the best of the English weapons were made of yew, carefully selected, thoroughly seasoned, and free from all blemish. The bow, when strung, was curved, the string standing about 6 inches from the middle of the bow. The arrow was also made with great care and precision. The best of them were perfectly straight, uniform in diameter throughout, tipped with a metal point, and feathered at the opposite end so as to make them fly true. Peacock feathers were generally used for this part of the arrow as the web of the feather is tough and retains its shape well.

The Indian arrow-maker was an exceedingly skilful craftsman. It was a hard day's work to make one arrow. The stems of the reed, *Phragmites vulgaris*, straight willow wands, the so-called white cedar or arbor vitae, the red cedar, striped maple, and many other woods were used. The material was carefully selected, seasoned with care, scraped down to uniform size, straightened by laying on a hot, grooved stone and bending to take out slight irregularities. The tip of chipped stone or of fire-hardened wood was fastened in with sinew cord and glue and the feathers were applied to the base. Three half-feathers were bound on equidistant from each other by sinew cord or

vegetable fiber. The shaft of the feather lay parallel to the long axis of the arrow or perhaps slightly inclined—the latter to make the arrow rotate as it flew. Among some savage tribes the arrowheads are barbed with thorns, fish spines, or porcupine quills to inflict as bad a wound as possible and to make them difficult to withdraw.

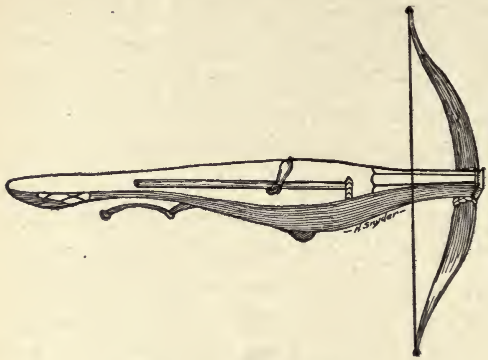


Fig. 52.—The crossbow

The crossbow was used in European armies as an improvement on the bow. A very strong bow was set at the end of a grooved stick. A small windlass at the other end drew back the string which could be released by a trigger. The arrow or bolt lay in the groove and was driven at the foe or game by the bowstring. The crossbowmen made a formidable part of the army (Fig. 52).

Fig. 53.—An archer in correct position.

The bow and crossbow as weapons in war and in the chase were replaced by the gun, when powder was introduced into Europe. Archery still exists, however, as a national sport among many peoples. The Royal Scottish Archers, the Woodsmen of Arden, and similar organizations still keep alive the use of the bow and arrow in England, and there are several archery associations in this country. It is no mean art to acquire—this handling of such a powerful bow (Fig. 53). The

bow is held about its midpoint in the left hand, the arm fully extended. The arrow is laid upon the first finger of the hand that grasps the bow, the notch of the arrow is placed upon the bowstring at its midpoint. Three fingers of the right hand are laid upon the string, one above the base of the arrow, two below. Just the tips of the fingers are on the string. The string is then pulled back, the base of the thumb going back against the cheek. The bowman then quickly sights along the arrow and releases the arrow by a movement of the wrist, turning the hand slightly to the right.

It requires a strong arm to pull back one of these bows until the head of the arrow is drawn back to the bow, and when released the arrow flies with great speed. The archer ordinarily wears leather caps for the fingers of the right hand that hold the bowstring and wears on his left arm a leather protector so that the bowstring when released will not injure the arm. The archer must of course allow for the direction and force of the wind and for the drop of the arrow in response to the pull of gravity when he is shooting at long range. The sport is a very attractive one and may be begun in a very simple way. Directions for making the beginner's bow and arrow, the crossbow, and the target are given in the *Field and Laboratory Guide in Physical Nature-Study.*

When a bow is bent, then springs back to its original shape when released, the wood is manifesting what is called elasticity. It is a familiar property of many substances. It is the elasticity of the steel in the watch spring that keeps the watch running, the elasticity of a rubber ball that makes it bounce, the elasticity of the air in the automobile tire that makes the machine so springy, the elasticity of the wood that makes the springboard toss one into the air. The molecules of solid substances are definitely arranged and spaced in relation to each other, so that the solid in many cases seems to resist any distortion of this arrangement. This does not mean that the molecules are fixed, for they are moving with tremendous rapidity in a tangle of interweaving pathways, yet on the whole the general pattern

of their arrangement remains constant. When this arrangement is disturbed the elastic body tends to resume its normal condition the moment the strain is removed and rebounds with as great a force as was applied to produce the distortion. Similarly, gases are made up of molecules much more widely spaced than those of solids or liquids, and these molecules are moving in relatively wide pathways with still greater speeds than those of solids. When the gas is compressed or crowded into smaller space, moving molecules repel each other more forcefully and hit the sides of the container much more frequently, because there are more of them moving in a given space, and so they exert upon the walls of the container an ever increasing pressure. Gases exhibit elasticity to perfection.

Various engines of war from the days of the primitive bowmen to the present have largely depended upon this property of elasticity for their efficiency. A device in use by ancient people was the catapult (Fig. 54). It consisted of a heavy, inclined plank with one end fixed firmly in a framework, the other free to move, and levers and pulleys so mounted that the free end of the plank could be pulled back until it was bent like one end of a huge bow. A great rock was then placed on this end, which was suddenly released, throwing the missile at the enemy. The huge plank was bent back by the labor of many men working with levers or windlass for considerable time, and this energy stored in the bent plank was suddenly released to act upon the rock.

These ancient engines of war were replaced by the gun when powder was introduced into Europe from China. Just when it was discovered there is not known, but old pictures of naval engagements show the vessels obscured in clouds of smoke, presumably made by the firing of guns many centuries prior to the introduction of powder into Europe. This event occurred in the fourteenth century. The early gun was a metal tube on the end of a straight stick. The powder was touched off through a small hole in the base of the tube by means of a lighted stick.

This gun could not be aimed with accuracy, but was merely pointed in the general direction of the enemy. From this primitive arm to the modern high-powered rifle or the great coast-defense guns is a far cry, and yet the steps have been merely improvements on the primitive weapons, not the application of new principles.

The force exerted on the bullet in the gun is that of the elasticity of the gases formed when the powder is burned. Gunpowder consists of a mixture of several solids; charcoal, sulphur, and saltpeter have been the ones most commonly used. When charcoal burns it unites with the oxygen gas in the air and forms the gas known as carbon dioxide. Saltpeter is a substance

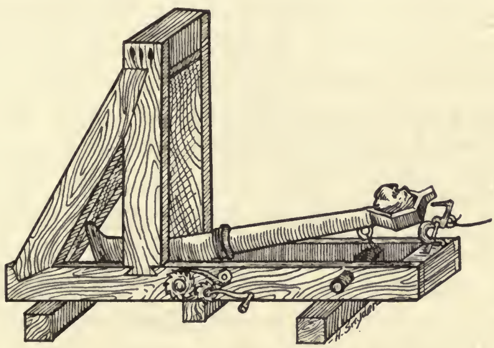


FIG. 54.—The catapult

containing a large amount of oxygen which it readily gives up. When the gunpowder is exploded the supply of oxygen, to combine with the carbon, is thus obtained, not from the air, but from the solid saltpeter. Sulphur and oxygen also readily unite to form a gas, and they unite at a considerably lower temperature than do carbon and oxygen; the sulphur, therefore, is put into the gunpowder so that it may be readily touched off. When heat is applied to the gunpowder the oxygen of the saltpeter combines with the sulphur and the carbon to form gases that occupy a large amount of space. The gases formed occupy at atmospheric pressures from 300 to 500 times the space occupied by the solid substances of the gunpowder. A small quantity of

gunpowder set off in the open does not explode but merely burns rapidly. If, however, this same gunpowder is put in a confined space as it is when rammed down in the gun barrel and then touched off, the gases formed need to occupy so much more space than the solids that the elastic force exerted is very great. The bullet, therefore, is hurled out of the gun barrel with great speed. If the powder is confined in a hole bored in rock and then touched off the expansive force of the gases is so great it bursts the rock.

The first crude gun was rapidly improved. The metal tube or barrel was fitted to a stock that was shaped so as to rest against the shoulder, enabling one to aim the piece and lessening also the effect of the recoil. In some of these early guns a small, toothed, steel wheel, bearing upon a piece of flint or pyrite, was rotated rapidly by a little crank, so furnishing the spark that set off the powder in the pan. Later a hammer carrying a piece of flint struck a piece of steel so producing the spark (Fig. 55). The flintlock musket was the arm of the British army until 1844. Most of these old guns were loaded from the muzzle. The charge of powder, as also the ball, was held in place by wadding and was rammed down with the ramrod.

The next improvement of prime importance was the substitution of a percussion cap for the flint and steel. The hammer struck the cap which was set on a hollow post over the powder charge. The cap, a small, cup-shaped metal affair, contained a substance that when struck with the hammer exploded and drove a flame down to ignite the powder. This improvement was used on sporting guns for some time before it was used on the guns furnished the armies, for it was an expensive proposition to change the type of gun for an entire army.

Next came the breech-loading gun. The breechloader was devised long before it came into general use, in fact there were breech-loading guns made back in the fifteenth century, but it was always a difficult matter to make the breech so tight that the explosion would not blow it out. When this was finally

accomplished, the breechloader came rapidly into use, for it could be loaded so much more rapidly than the old muzzle-loading gun. A shell containing powder charge and bullet and with a percussion cap fixed in one end was introduced into the stock end of the barrel. The hammer struck a movable pin that rested against the percussion cap in the shell. The Prussian army was furnished such breech-loading guns at the time of the war with Austria, 1866. The war was of very short duration, for the new type of arm was so much more efficient than the old muzzle-loading gun that the Austrians were repeatedly routed with exceedingly heavy losses. This war was such a conclusive

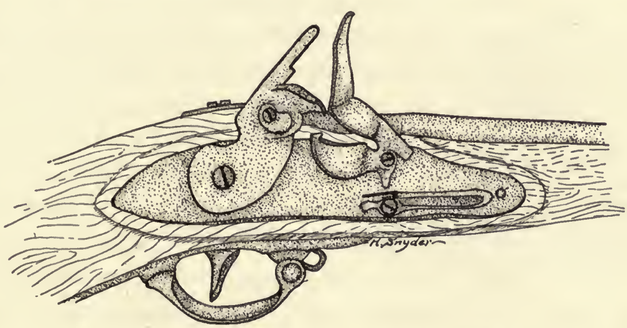


FIG. 55.—The flintlock of an old musket

demonstration of the value of the breechloader that all the European nations proceeded to furnish these guns to their armies.

In the old guns the bullet was a leaden ball, slightly smaller than the bore of the barrel. It could not be fired at long range with any great accuracy for it struck first one side of the bore, then the other, as it was shot out and never went very straight. It was so large in cross-section it offered great resistance in its passage through the air, and its speed was rapidly checked. When attempts were made to use long, slender, sharp-pointed bullets to overcome this difficulty, they would go tumbling end over end through the air in irregular courses.

Finally, however, a device was found to overcome this. The gun barrel was grooved with spiral grooves. The base of the bullet was hollowed out and a sharp-pointed metal or wooden plug was set in the hollow so that the explosion of the powder drove in this peg, expanding the base of the bullet so the lead was forced into the grooves, thus giving the bullet a twisting motion about its long axis as it sped away from the gun, and it would keep going straight. Moreover, this device made the bullet fit the barrel tightly so no gases escaped around it as had happened when the loosely fitting ball had been used. Now there are added to the gun a magazine to hold a number of shells, a shell ejector, and accurately gauged sights.

The old muzzle-loading guns could not be fired very rapidly for the loading process was slow and one must stand up to accomplish it. Loading at the breech was quicker, and it could be done lying flat on the ground, so offering little target for an enemy to shoot at. Added speed in firing was possible with the invention of the magazine gun. Several cartridges are carried in a chamber in the stock. By the movement of a lever the empty shell is ejected and a loaded one is brought up from the magazine and slid into position ready to fire. In some rapid-fire machine guns the force of the recoil is made to eject the old shell and bring the next one into position. The shells are introduced in a long belt, and the gun keeps up a continuous fusillade of shots, a steady roar of discharge.

When the bullet leaves the gun, gravity at once begins to pull it down to earth at a rate of 16 feet the first second. The bullet fired from the modern high-powered rifle has a velocity when it leaves the muzzle of a half-mile a second. If the gun is aimed at an object only 100 yards distant, the bullet is pulled down by gravity only a few inches before it reaches its mark. But if the object is a half-mile away, then the bullet must be fired several feet above the object in order to hit it. The sights in the modern gun can be set for various distances, and the muzzle is elevated more and more for increasing distances. In recent tests of

machine-made ammunition manufactured in an American arsenal the 3-foot bull's-eye was hit 176 times in succession at a range of 800 yards, and 41 times in succession at 1,200 yards, over two-thirds of a mile.

The early cannon were made of wood, later of brass, were muzzle-loaders, touched off with a blazing torch, and the shot were at first stones, then solid iron balls. They were small, primitive affairs, inaccurate in their fire, and were first used in Europe with no expectation of killing people but merely to scare the horses on which the armored knights were riding. In the famous "Constitution" that won renown in our War of 1812, the guns were about as long as a man, mounted on crude, wooden-wheeled carriages, and the muzzle was lowered by driving a wedge-shaped, wooden block in under the butt of the gun (see Fig. 56).

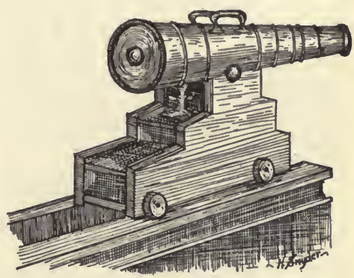


FIG. 56.—An old cannon on its wooden carriage.

The improvements in the cannon followed along the same lines as the changes in the small arm. Breech-loading took the place of muzzle-loading. The round shot was changed to a pointed cylinder which was given a rotary motion by spiral grooves in the barrel. Now the great guns are sometimes 75 feet long, and throw a shell that weighs more than a ton 20 miles. The bore of such a gun is 12, 14, or 16 inches. Naturally, such a gun could only be manufactured when machinery had been devised for handling it, forging it, boring it accurately. Ways have to be devised also for strengthening it, for the pressures of elastic gases formed by firing the charges of powder—hundreds of pounds—are terrific. The gun must resist a bursting pressure of 50 tons or more per square inch.

The same elasticity of gases that is used to work such awful devastation in war is also immensely serviceable to man in peace.

Powder and other more powerful explosives are essential in blasting out coal, the ores of the metals in the mine, the stone in the quarry. Air compressed by powerful engines is sent down by iron pipes and hose into mines and quarries to furnish the power for drills that make the holes in which the charge of

FIG. 57.—A drill operated by compressed air in a quarry

explosive is placed to smash the rock into pieces that can be handled (Fig. 57). The hand-power air pump is familiar to most boys and girls who have ridden a bicycle and to the automobile driver, for by its aid the tires are inflated. The principle of operation is very simple. A piston-head fits a metal cylinder tightly. In this head is a valve that lets air into the cylinder on

the upstroke, but closes when the down stroke begins. A second valve lets the air out of the cylinder on the down stroke into the tire. As more and more air is pumped into the tire the elasticity of the air increases and so the pressure against the inner wall of the tire is greater and greater. When the valve is open between the cylinder of the pump and the tire, the air in the pump is exerting the same pressure on the plunger and walls of the cylinder as is exerted on the walls of the tire. If the plunger were larger the upward pressure upon it would be difficult to overcome, and it would take more power than the average person has to force the plunger down. Sometimes the automobile pump is made of two cylinders with a plunger in each. The upstroke of the plunger in the large cylinder drives the air into the small cylinder, and the down stroke drives the somewhat compressed air into the tire. The cross-section of the plunger in the small cylinder may have an area of, say, only one-quarter square inch. It would have to be pushed down, therefore, only with a force slightly exceeding 15 pounds to overcome a pressure in the tire of 60 pounds per square inch. Yet the large cylinder has capacity enough so that the tire can be pumped up quite rapidly.

CHAPTER VI

FIRE AND ITS USES

Fire is a good servant and a bad master.—OLD DANISH PROVERB

It is difficult to say which of the discoveries primitive man made in his gradual conquest of nature was most important, yet certainly the ability to make and utilize fire was one of the most important, possibly the most important. It added very greatly to his creature comforts, and opened up the way to a multitude of added discoveries in the arts and industries.

Undoubtedly he came to use fire before he knew how to make it. Possibly he took it from some red-hot lava stream, some flaming vent of natural gas that flowed in his neighborhood, from a forest fire started by lightning. Once he knew its value, he guarded the glowing embers with jealous care. It seems to have been one of the functions of the early priestly caste to keep the fire blazing, and that blaze may well have been regarded as sacred, so important was its continuance in the life of the community. Possibly the savage went to the sacred places to renew his own home fire. In the pioneer days in our own country it was no uncommon thing to go miles to the nearest neighbor to borrow fire to start the blaze on the hearth when it accidentally went out. Even in historic times savage peoples have been found who did not know the use of fire. Magellan in his exploring trips found such on islands of the Pacific.

In these modern days when we start a fire so easily with a match it is difficult to realize that the match is a recent invention, and that for many centuries flint, steel, and tinder box were used to start a fire, or possibly the fire stick, the fire drill, or some such cumbersome device. There are still primitive peoples that use the fire stick and fire drills. The former is a sharp-pointed stick

of hard wood that is held in the hand and plowed back and forth in a groove in a block of soft wood. A fine wood dust is thus made in the groove which is ignited as the friction of the two pieces of wood develops heat. The glowing spark is nursed with shreds of dry bark or punk, blown into flame, and so the fire is started.

The fire drill (Fig. 58) works in much the same way except that the stick of hard wood is given a rapid rotary motion while its point is pressed down into a shallow hole in the softer wood. Among some tribes this rotary motion is imparted to it while it is held between the palms of the hands. In other cases the thong of a bow is wrapped about the drill a time or two, and as the bow is drawn back and forth the drill is turned rapidly. The upper end of the drill rests against a leather pad or wood block placed against the chest. The operator of the drill kneels, bends over the drill, and so has both hands free to operate the bow or thong.

FIG. 58.—Parts of a fire drill and its use

The first match was devised by Chancel. It consisted of a bit of wood tipped with a gum containing chlorate of potash and sugar. This was dipped into strong sulphuric acid to ignite it. Most persons preferred to carry flint and steel and tinder box rather than sulphuric acid, for the latter burns badly and makes holes in clothing wherever it touches. So this type of match was never widely used. It was not until 1835 that the

friction match was invented. It rapidly replaced the flint and steel. The bit of dry wood is tipped with a paste containing some substance that ignites at low temperatures, such as phosphorus, one that burns readily like sulphur, and a substance that parts with its oxygen easily as do potassium chlorate or manganese dioxide. The friction of striking the match generates heat enough to ignite the phosphorus, which lights the sulphur, which makes heat enough to start the wood burning. The white phosphorus used in these early matches was poisonous, and sometimes a child was killed by eating the heads of matches carelessly left where it could get them; and the workers who made matches were affected by a very painful disease, a result of inhaling the fumes. The sulphur used produced choking fumes when the match burned. So the phosphorus is now replaced by substances like antimony sulphide or phosphorus sulphide, which also ignite at a low temperature but are safe; and paraffin is used in place of sulphur. In the safety match the potassium chlorate and antimony sulphide or similar substance is used in the head, and the red phosphorus is present in small quantity in the prepared surface on which the match must be scratched to light it readily.

Break a lump of sugar into smaller lumps and these into still smaller bits. You might think you could keep on doing this indefinitely if eyes were sharp enough to see the finer particles and fingers were skilful enough to use fine-pointed instruments to do such a delicate job. But the chemist and physicist tell us that this is wrong and that sugar (and, in fact, every substance) is made up of very minute particles called molecules that cannot be broken up without destroying the sugar as such. True, the molecule is made up of still smaller particles, the atoms, but when the sugar molecule is broken up into its atoms we have carbon, hydrogen, and oxygen, simple substances having properties quite unlike sugar.

Now atoms of substances like carbon, hydrogen, and oxygen have a very strong attraction for one another and tend to rush

together in intimate associations or molecules like sugar. Oxygen atoms have a strong attraction for carbon atoms, uniting vigorously to form carbon dioxide. Similarly, oxygen and sulphur unite to form sulphur dioxide, and phosphorus and oxygen unite. These atoms rush together with such energy that the molecules are set into rapid vibration. So heat is generated together with light, and we say the substance burns. A burning substance as usually understood is one whose atoms are uniting with oxygen so rapidly as to produce heat and light. Oxidation, the union of a substance with oxygen, may go on slowly and no heat or light be noticeable. When iron rusts, it is uniting with oxygen, but slowly. Other substances may unite chemically so rapidly as to produce heat and light. Thus, if powdered antimony is sprinkled into chlorine gas there is so rapid a union of chlorine and antimony to produce antimony chloride that heat and light are produced. We might say the antimony burns in an atmosphere of chlorine.

It is a simple matter to generate oxygen and to collect it in quantity (see *Field and Laboratory Guide in Physical Nature-Study*, p. 60). When a splinter of wood is lighted and allowed to burn a moment, then the flame is blown out, leaving a glowing ember, and this is stuck into a jar of oxygen, the splinter bursts into flame again. A bit of sulphur when lighted burns sluggishly in the air, which is only about one-fifth oxygen, but introduced into a jar of oxygen it burns freely with a bright light. Iron picture wire, which does not burn at all in air, burns vigorously in oxygen, throwing off showers of sparks.

The explanation of the process of burning is now so simple that the child may get a reasonably clear notion of it. Yet it quite mystified our great-great-grandparents. In their day the four elementary things were earth, air, water, and fire. Everything was made of these mixed in varying combinations and proportions. True, the notion of atoms had occurred to the old Greek philosophers, but it had been a shrewd guess rather than a scientific theory based on anything like adequate evidence. Even this was lost sight of during those dark ages that followed

the submergence of the old civilization by the hordes of barbarians. Joseph Priestly, an English clergyman, who also delighted to make chemical experiments, discovered oxygen (1774), and described its properties with considerable accuracy. He and the chemists of his time were beginning to realize that these four so-called elements were not elements at all. Priestly showed that one of the substances in the air was oxygen, or as he called it "dephlogisticated air." He used the term air as we use the term gas. Thus hydrogen he also knew as "inflammable air," and carbon dioxide as "fixed air," because it was fixed or united with other substances in limestone. He believed as did most of the chemists of his day that fire was due to the escape of an "inflammable principle" called phlogiston from substances when they burned. Since oxygen would not burn as inflammable air did, he thought the phlogiston had been in some way taken out of it, so it was "dephlogisticated."

Lavoisier, a French contemporary of Priestly, proved that when a substance burned it gained weight rather than lost it, and so must take up something instead of giving it off. He was convinced that burning was the union of oxygen with the burning substance. Priestly had visited Lavoisier and talked this matter over with him and yet the old notion of phlogiston was so fixed in his mind he could not see the truth.

We really owe a very great deal to the scientists who devote themselves to discovering truth for its own sake. It is only when we understand the nature of things and of the forces that operate about us that we can make rapid progress in the invention of those devices that make life easier and more agreeable.

When the nature of fire was understood there soon came discoveries of new applications of it to the arts and industries and improvements in the old ways of doing things. Primitive man warmed himself beside a fire built in the open, and cooked his food over it too. When he built a fire in his cave or shelter the smoke made its escape as best it could. Cottager and nobleman alike among our Anglo-Saxon forebears must choose

between cold dwellings and suffocating smoke. The chimney did not appear in England until the thirteenth century and then it was merely a hole in the wall over the fireplace. The built-up chimney with extension above the roof is a modern convenience. The fireplace was the best means of heating the house and of cooking until 100 years ago, when the iron stove came into general use. Brick or tile stoves were used back in the Middle Ages—really a fireplace set out in the room. Cardinal Polignac, of France, invented an iron stove in 1709, but it was Benjamin Franklin who devised improvements that made it really practicable (1745).

We have seen in an earlier chapter why the hot-air balloon rises. The heat expands the air in it so that some of it must flow out. The balloon, therefore, contains less weight of air than a corresponding volume of surrounding air. Since the upward pressure on the underside of the balloon is greater than the downward pressure on its upper surface by an amount equal to the weight of the air the balloon displaces, the balloon rises, provided this difference in weights is greater than the weight of the balloon and its trappings.

In a similar way the column of air in the chimney is heated by the fire in the stove or the fireplace, and, expanding, it overflows. The column of air in the chimney, therefore, weighs less than a corresponding column outside because there is less of it. The air in the chimney is forced up and out of its top as the cool and heavier air rushes in at the bottom. This air is in turn heated and so the draft up the chimney is continuous.

An efficient fireplace is built with slanting sides and rear wall so as to reflect the heat out into the room, with a large smoke outlet whose cross-section area is not less than one-eighth that of the fireplace opening, and with the front edge of the latter opening considerably below the smoke outlet so smoke will not get out into the room. Its depth should be about the same as the length of the rear wall and the height of the front opening not over three-fifths of its length (see diagram, Fig. 59).

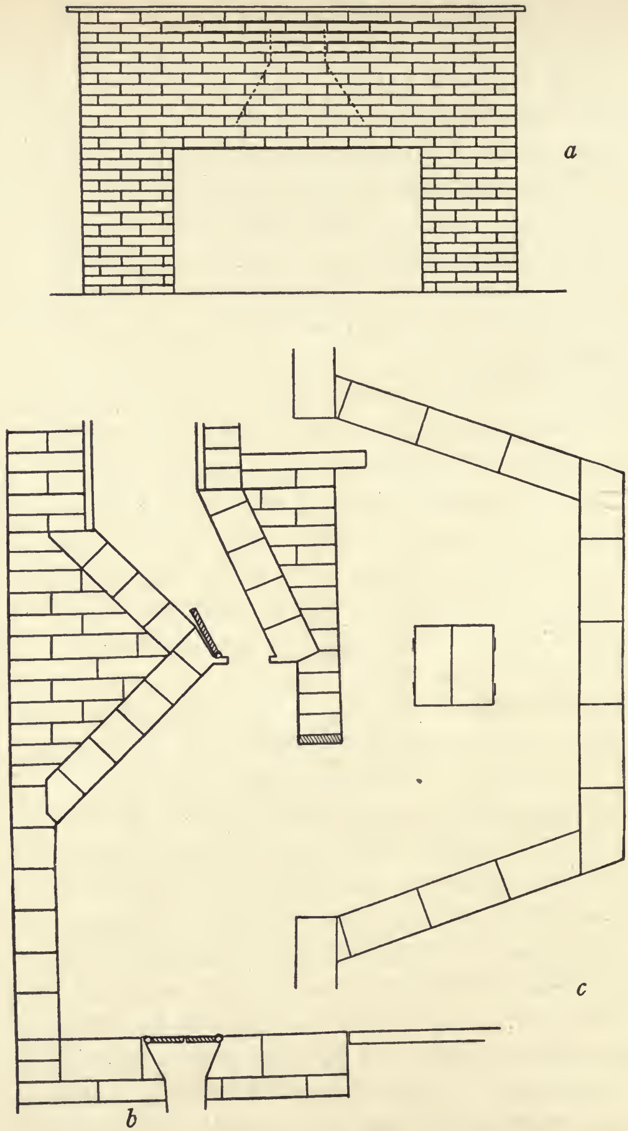


FIG. 59.—A fireplace: (*a*) face; (*b*) vertical section showing plan; (*c*) floor plan

The stove has numerous advantages. As its radiating surface is relatively large, much more of the heat from the fire is radiated into the room, and much less goes up the chimney. By dampers set in the stovepipe and drafts below the fire box that may be opened and closed, the flow of air through the fire can be controlled and so the rate at which the fire burns. On the cook stove the utensils may be heated by contact with the hot surface, and not get covered with soot as they are in cooking over an open fire. Certain metals are very good conductors of heat, such as aluminium and copper, while others conduct it poorly. It is an advantage to have the heat conducted rapidly to the thing in the kettle or pan that is to be heated. So the teakettle often has a copper bottom, and cooking utensils made of aluminium are often used.

You may readily demonstrate that there is a difference in the heat conductivity of various substances. Take a piece of No. 18 copper wire 8 inches long and one of iron wire of the same size and length. Twist them together at one end so as to form a V. Fix a little ball of paraffin or beeswax as big as a pea on each wire halfway from the point of the V to the end. Holding the V by its ends stick the point of the V in a flame, the arms horizontal. Continue holding it thus until both wax balls fall off. You will find that the one on the copper wire melts enough to fall long before the one on the iron wire, for copper is a better heat conductor than iron. We shall find that it is also a much better conductor of electricity.

We put coverings of poor conductors like asbestos felt on steam pipes and furnace pipes to prevent loss of heat. We build the fireless cooker (see *Field and Laboratory Guide in Physical Nature-Study*, p. 58) by inclosing the pail in which the cooking is to be done in a box packed with some non-conductor like chopped straw or else surround it with several air spaces separated by sheets of asbestos. Dry air is itself a very poor conductor. So the thermos bottle is merely a bottle surrounded by several air spaces, or, better still, spaces in which there is no

air. These, of course, must be air-tight. Any hot substance in the bottle cannot lose heat to the surrounding air, while if the bottle contains a cold substance the heat of the surrounding air cannot get to it to warm it. We put a storm sash on our windows to inclose a layer of air between the window and the storm sash. These numerous substances in the path of the radiating heat tend to reflect it and prevent its escape, for heat is reflected just as is light. Put a thermometer bulb at the point at which the light from a lamp is brought to a focus by a concave mirror and the mercury rises rapidly.

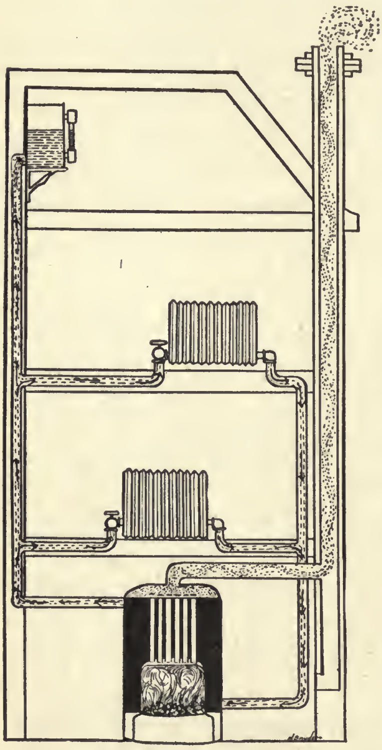


FIG. 60.—Diagram of a hot-water plant

Now, too, to avoid dust and dirt in our homes the heating plant for the house is often put in the basement. Hot-air pipes from the furnace conduct the heated air to the rooms above on the same principle that the chimney carries the hot air up. In the same way the hot-water pipes conduct the hot water up to the radiators and as it cools off in them, it flows back to the heater, so forcing up the hot water. In the hot-water system an expansion tank must be used, because when the cold water is heated it expands and unless there were a chance for an overflow it would burst the pipes and radiators (see diagram, Fig. 60).

In the steam-heating plant, the water is boiled in the basement, the steam goes up through pipes to the radiators to warm

the house, there condenses to water again as it cools, which flows back to the heater through return pipes.

Since dry air is a poor conductor of heat it is important to keep the air in the house moist; otherwise the heat from the radiator does not readily pass to your body. It is quite as important to have a hygrometer in the living-room to see that the air is moist as it is to have a thermometer to see that the temperature is correct. One feels comfortable when in fairly moist air at 68° F., whereas in dry air the temperature may have to be 75° to give the same feeling of comfort. Evidently it is good economy to keep the air moist. This may be accomplished by a water pan kept well filled in the hot-air furnace or by pans of water hung on the radiators in hot-water or steam-heating systems.

Just as the fire in the fireplace or stove causes the heated air to rise in the chimney because the heavier cool air forces it up, causing a draft, so any mass of heated air surrounded by cooler air rises as the cooler air pushes it up and comes in with a rush as it takes its place. A great fire in the open heats the air above it, and the surrounding cool air blows in as the hot air rises, causing local winds (Fig. 61). When the air becomes heated over any area on the earth as over a desert, it rises and the cool air around it blows in. The equatorial regions of the earth are hot, and the air over them rises. We do not notice rising or falling air as a wind—only air that is moving horizontally along the surface of the earth. So in the equatorial regions there is a belt of calms. The cooler air flowing in from north and south along the surface of the earth on the edges of this belt of calms makes winds. These do not blow straight from the north or south, for the air is coming from regions where it is rotating with the earth at less speed than that of the equatorial region. Because of inertia the inflowing air tends to keep its slower rate of rotation, and the more rapidly moving equatorial region slips along under it from west to east, so that the winds seem to come from the northeast north of the equatorial belt of

calms, from the southeast south of it. These constant winds are known as the trade winds.

The temperature of the air is not the only factor that determines its weight or pressure. If it is carrying a great deal of moisture, it is lighter than when it is dry, because the water vapor displaces air and the latter is heavier than the former.

FIG. 61.—A fire. Note the piece of roofing carried up by the hot air

The combination of these factors with others produces belts of high pressure from which the trade winds move toward the Equator, and other less steady winds known as "the westerlies" which move toward the poles. The air does not move due north and south toward the poles, but for the reason already indicated these constant winds blow from the southwest in the Northern Hemisphere, and from the northwest or nearly west in the

Southern. The course of both trades and westerlies is further made irregular by the irregularity of the distribution of land and water. Still they are sufficiently regular to be of much importance in commerce, and were much more so in the days of sailing vessels.

In addition to these general air movements from temperate regions toward the Equator and poles along the earth's surface and in the reverse direction high up in the air, there are local winds produced as variations in heat and moisture develop local areas of high and low pressure. The winds blow along the earth's surface from the high-pressure areas to the low-pressure. Daily reports of atmospheric pressure are sent from many stations all over the country to the Weather Bureau at Washington so that with a knowledge of the location of high- and low-pressure areas, the country over, the probable direction of the wind at any locality can be predicted. If the difference in pressure between adjacent high and low areas is very great, the winds will be strong; severe blows can be foretold in time to warn vessels and persons interested in such forecasts.

When moist air is rising into the upper atmosphere which is cool, the moisture will be condensed to form clouds, and if the rising air is very moist, the condensation produces rain. The air coming into a low-pressure area from the south is usually warm and moist; therefore clouds and showers may be expected on the south side of a low-pressure area. On the other hand, the air coming in from the north is cool and dry, and since it grows warm as it moves southward it can take up additional moisture. On the north side of a low-pressure area fair weather may be expected. Having reports from many stations on the humidity of the air as well as on temperature and pressure, the Weather Bureau embodies these in the daily weather map on the basis of which the predictions are made (Figs. 62 and 63, pp. 158, 159).

Improved industrial processes offer very many illustrations of the way in which our knowledge of fire and its methods of control have contributed to the advance of civilization and the

multiplication of creature comforts; one must suffice here. Primitive man used chipped-stone implements because he did not know how to obtain anything better. Our American Indians used copper to some extent. They found bits of float copper brought by the glaciers from the great deposits in northern Michigan or in similar locations, and fashioned an occasional spear head or knife from it, but the Indian was still largely in the stone-implement stage when Columbus came to this shore. There came a time when early man learned how to extract the

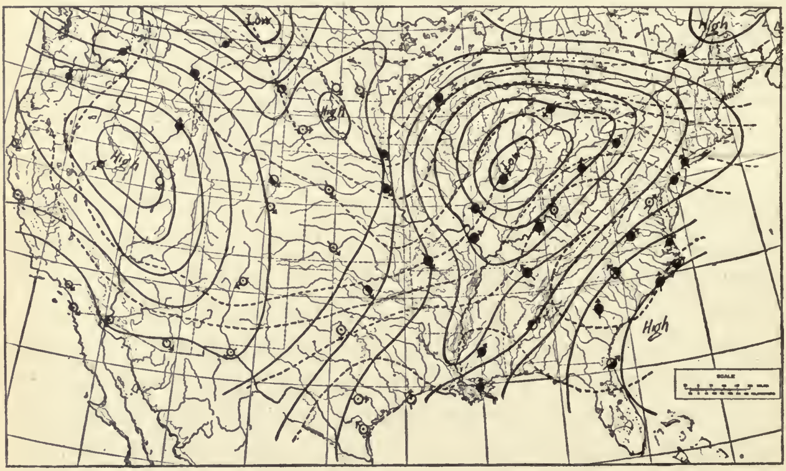


FIG. 62.—A weather map of the United States

metals from their ores. That was so very long ago we do not know what his methods were. But following the man of the chipped-stone age and of the polished-stone age, there came peoples who made bronze utensils, and that time is known as the Bronze Age. Bronze is made by melting together tin and copper. So those people must have know how to extract tin from its ores. We know the tin mines of Cornwall, England, were worked during Roman times and probably very much earlier.

Then came the age of iron implements. Some savage tribes have today very crude processes for extracting iron from its ore.

Possibly the process was discovered when some savage used an easily reduced ore of iron like siderite (see p. 50) to build a fireplace, and found after many fires a bit of iron in it that could be hammered out into serviceable shape. At any rate, the iron forge among some African and Asiatic tribes is today simply a hole dug in a high clay bank to serve as a fireplace in which a charcoal fire is built and bits of iron ore and limestone are added, then more charcoal, limestone, and iron ore, layer after layer. The wind may furnish the draft, or simple bellows made of the

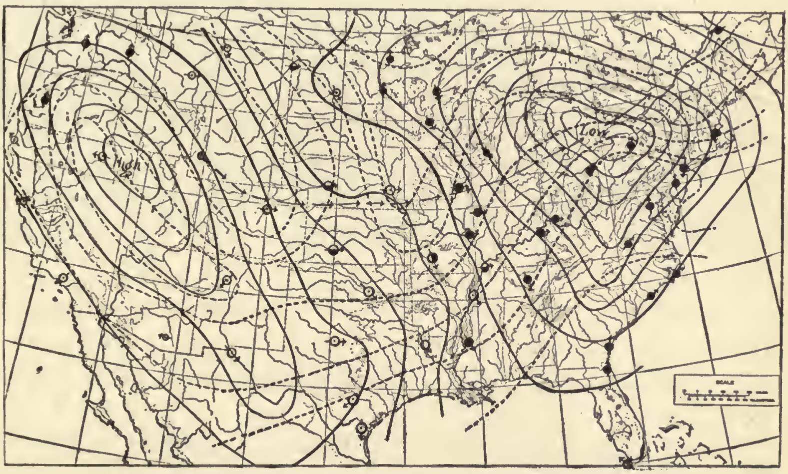


FIG. 63.—The weather map one day later than Figure 62

skin of an animal may be used. After the fire has been kept going for many hours it is allowed to go out, and at the bottom of the hole there is dug out of the ash and débris a bit of iron. Such a process of reduction is exceedingly slow. The quantity of iron produced is small and it, therefore, is very costly. Iron was, among early peoples, often used as money.

The modern furnace does not differ in principle of operation from such a primitive affair as that described. The ores of iron most commonly used are oxides of iron, chemical unions of iron and oxygen. They melt at high temperatures at which the

oxygen of the ore unites with the carbon present as charcoal or coke and forms gaseous oxides of carbon. Some impurities in the ore such as phosphorus and sulphur also unite with the oxygen to form their oxides, also gases, while others like silicon unite with the limestone or "flux" and form a glassy slag.

It was found as the furnace stack was made larger that the melted iron because of its weight sank to the bottom of the stack while the melted slag, being lighter, floated on top of it. The slag could be drawn off, and then the iron through a lower hole, and so the furnace could be run continuously instead of letting the fires go out to get the iron. The stack came to be larger and larger, was built of brick and lined with firebrick, and the bellows was operated by power. Still later a rotary fan was used to blow the draft into a furnace. The ores, flux, and charcoal were taken to the top of the stack by elevator, piled on a movable lid on the top of the stack, and fed into the stack when this lid was opened by machine power. When the iron was drawn off it was run into a trough in the molding-sand floor adjacent to the stack, and from this was led into small tributary troughs where it hardened into "pigs," so called because they lay side by side like a row of nursing pigs. Iron thus produced was called pig iron (Fig. 64).

There was a vent from such a stack carrying off into the air the inflammable gases. Now these are brought by great pipes down under the boilers to make steam for power to handle the ore, flux, and charcoal or coke, and under great steel stoves that heat the air to be driven into the furnace so the fires in the stack may not be cooled by the entrance of cold air. The pipes that carry this hot-air blast into the furnace have their points cooled by a jacket of constantly changing water so that they will not melt in the intense heat. The ore, flux, and fuel are handled by machinery, so that human labor is reduced to a minimum.

All the products which distil off as the wood is heated in the charcoal kilns (Fig. 65) or the coal is made into coke in the ovens, and which at one time were turned into the air as wastes, are now

FIG. 64.—A blast furnace. Courtesy of the Pioneer Furnace Co., Marquette, Michigan.

FIG. 65.—A line of old-fashioned charcoal kilns

caught, and by proper treatment are turned into valuable commercial products. Thus, wood alcohol, acetic acid, creosote, tar, heavy oils, dyes, and many other valuable by-products are saved. Indeed, it is said that the by-products are now so valuable that they pay the expense of operation, and the iron itself is sold at a clear profit. In many furnaces the iron is no longer run into "pigs" but is received as it runs from the stack in caldrons on cars that take it to the puddling furnace or Bessemer converters, where it is made at once into steel.

The improvements in the process make it possible now to produce more iron and steel in a single year than existed in the whole world when Columbus discovered America. Then all the iron existing would have made a pile 8×6 feet and less than a mile long; now, a year's output is a pile of like size that would reach from New York City beyond the Mississippi River! Consequently we use it lavishly, and its relative cheapness makes possible the immense quantity of labor-saving machinery now in use in factories, on farms, and in homes. It has made possible our great system of transportation, our railroads, locomotives, steel freight cars, great steamships, automobiles, and trucks. This is the age of steel.

CHAPTER VII

THE NATURE OF MATTER

In Nature's infinite book of secrecy
A little I can read.—SHAKESPEARE, *Antony and Cleopatra.*

As we noted in a previous chapter, the physicist believes that every substance is made up of very tiny particles called molecules, and that if these are broken up into their component atoms the nature of the substance is completely changed except in the case of elements. Thus a drop of water might be divided into smaller drops and these into still tinier droplets. But such subdivision cannot go on indefinitely. Ultimately a division would give molecules of water. If these were again split, the product would no longer be water but hydrogen and oxygen, the two elements that make up water whose properties are entirely unlike those of water. The physicist believes in molecules although he has never seen them, because this molecular theory enables him to explain and predict the many physical phenomena. Even elements exist in molecular form and while, when the molecules of an element are split into the atoms, we have no new substance, yet the properties of an element in its atomic state are usually quite different from its properties in the molecular state.

In spite of the fact that the molecule is so small it has never been seen, yet its size has been calculated from experimental data, with reasonable accuracy. A hydrogen molecule has a diameter of about one eleven-billionth of an inch and weighs about one ten-sextillionth of an ounce, figures that are meaningless, because they are so far removed from experience. It is difficult to put them in terms that are comprehensible. A bubble of hydrogen gas under ordinary conditions with a diameter as great as that of the cross-section of a pin would contain

fifteen quintillion molecules. There would be some three million of them just along the line of its diameter. If such a bubble were magnified to the size of the earth the molecules would be somewhat over an inch in diameter (1.1). This is a magnification of about twelve and a half billion diameters. The most powerful microscopes now at our disposal magnify about ten thousand diameters.

These molecules are not standing still but, due to the radiant energy imparted to them in the form of heat, they move in straight lines at the rate, in the case of hydrogen, of a mile a second, or in our magnified bubble at a rate over 12,000,000,000 miles a second. Oxygen gas with a molecule whose mass is sixteen times as great travels only a quarter as fast. Such molecules are, therefore, constantly bumping into each other and against the sides of the container, and so must constantly be shifting the direction of their movement. Hydrogen molecules at ordinary conditions of temperature and pressure average about 10,000,000,000 collisions every second. It is the constant impact of the molecules of a gas against the walls of the containing vessel that makes the gas exert its pressure.

The velocity of molecular movement increases with an increase in temperature and diminishes with its decrease. It is calculated that all molecular movement would cease at what is called absolute zero, 271.3° C. below the freezing-point of water, a temperature which has recently been nearly achieved in the laboratory. The molecules move less rapidly and are closer together in liquids than in gases and are still more closely spaced and move still less freely in solids. When great quantities of heat are absorbed without a rise in temperature, as occurs when a solid is changed to a liquid, as in the melting of ice, or when a liquid is changed to a gas, as in the change of water to steam, the absorbed heat is used to impart the more vigorous motion to the molecules, which necessitates their wider spacing and the consequent increase in volume of the substance changed. When the reverse process goes on, the latent heat again becomes sensible.

So it is quite commonly observed that a thunder shower does not cool the air but makes the heat more oppressive, and that severe winter temperatures are moderated by a snow storm.

If the tiny bubble of hydrogen were to be magnified as indicated above, you would not see the molecules as solid objects like golf balls, for each molecule is made up of relatively small particles traveling in orbits or possibly oscillating in pathways. Just as we say that the solar system, the central sun and the bodies revolving about it, has a diameter of nearly 560,000,000 miles, though only a minute portion of this space is actually occupied by the sun, planets, and moons, so the bodies that compose a molecule really occupy but a small part of the space assigned to it. The molecule consists of atoms, two in the case of elements (or rarely one atom), moving in pathways about some center. In complex compounds a molecule may consist of hundreds of atoms. Each atom of hydrogen consists of a central mass carrying an excess of one charge of positive electricity and revolving about it one charge of negative electricity—a bit of disembodied force. The latter is known as the electron, the body that carries the positive charge, the proton. It is the pathways of these that occupy the space assigned to the atom, the diameter of which, in the case of hydrogen, is about half that of the molecule.

Protons and electrons are so small that they would still be invisible if the tiny bubble of hydrogen gas were only magnified to be as large as the earth. Suppose it were enlarged to a sphere with a diameter that of the orbit of the earth. Then the molecules would be some two-fifths of a mile in diameter, the electron about one-fourth inch in diameter while the proton would be one eighteen-hundredth of that. In spite of this disparity in size the mass of the proton is about 1,800 times that of the electron.

Chemists used to believe that there are eighty or more elements such as copper, iron, oxygen, which enter into various combinations forming compounds. Common salt, for instance, is a combination of the elements sodium and chlorine. And this

distinction between elements and compounds is still maintained. But now it appears that elements in turn are made of protons and electrons, and the difference in their properties is due merely to the difference in the number and arrangement of these component units in their atoms. The nucleus of every atom is made of one or more protons, each holding at some distance an electron that moves about the nucleus. Possibly the nucleus is made of both protons and electrons, but if so the protons are in excess, and it is the excess protons that hold the electrons that move about the nucleus. It will simplify matters here to consider only the excess protons and their attendant circling electrons.

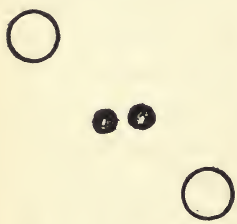


FIG. 66.—The helium atom. In this and the succeeding diagrams no attempt is made to represent relative sizes and distances accurately.

The atom of hydrogen, as we have seen, consists of one excess proton and one electron. The helium atom has two protons in its nucleus and two electrons that lie on opposite sides of this nucleus. These two electrons have pathways which are included in a sphere that is relatively distant from the central nucleus, just as was the case in the hydrogen atom. The electrons are symmetrically arranged with reference to the nucleus (Fig. 66). In all such cases the element seems to be relatively inactive chemically, and helium is a very inert gas. It is a very light gas, not as light as hydrogen, but it is used in place of the latter in filling balloons, for it is safer. It is obtained from natural gas. Hydrogen is very active chemically, and forms with oxygen an explosive mixture.

The lithium atom, the next in the series, has three protons in its nucleus and three electrons about the nucleus, two in a sphere similar to that of helium, the third in a sphere twice as far from the nucleus as the first sphere. Its molecule is, therefore, larger than that of helium. Then come beryllium with four electrons, boron with five, carbon with six, nitrogen with seven, oxygen with eight, fluorine with nine, and

neon with ten. In each of these, two of the electrons are in the inner sphere, the remainder in the outer. Now neon has eight in the outer sphere, which seems to be its capacity, and these eight are apparently symmetrically arranged. Neon like helium is very inactive and ends the second series. In the first place we have helium with two electrons in a sphere about the nucleus, then

Lithium	Beryllium	Boron	Carbon	Nitrogen	Oxygen	Fluorine	Neon
2+1	2+2	2+3	2+4	2+5	2+6	2+7	2+8

These form what may be termed the second series, the electrons arranged in a second sphere. Again we have a series of eight elements, the third series, each one with one additional electron in its atom, and these seem to be in a third sphere nearly coincident with the preceding one, as follows:

Sodium	Magnesium	Aluminium	Silicon	Phosphorus
2+8+1	2+8+2	2+8+3	2+8+4	2+8+5
	Sulphur	Chlorine	Argon	
	2+8+6	2+8+7	2+8+8	

In argon the third sphere is full, 2+8+8. The fourth series is a double series, the electrons being in a sphere with a radius three times that of the helium electrons, therefore capable of holding more electrons. The fourth series ends with krypton. This has two electrons in the first sphere, eight in the second, eight in the third which is nearly coincident with the second, eighteen in the fourth, thirty-six altogether. The fifth series is also a double series, the electrons being in a sphere that is nearly coincident with the fourth, and also has room for eighteen electrons. It ends with xenon, which has fifty-four electrons. The sixth series is a triple series. The electrons are in a sphere with a diameter four times that of the first sphere, which sphere therefore has capacity for $4^2 \times 2$ electrons or 32. Niton, with eighty-six electrons, ends the sixth series. The added electrons of the seventh series are in a sphere coincident with the sixth and therefore with a capacity of thirty-two. However, the later

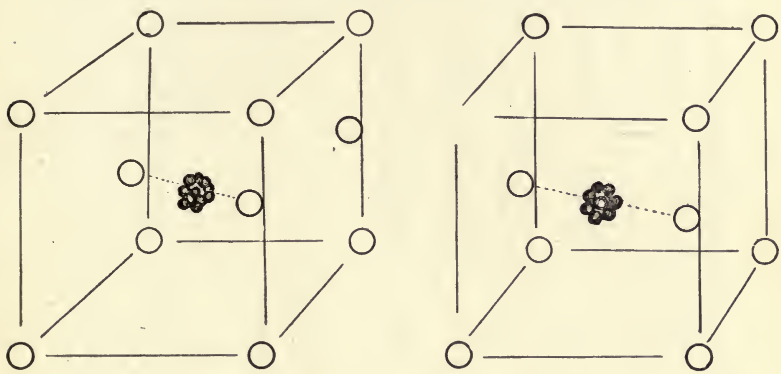
elements in this series are unknown, uranium with ninety-two electrons in its atom being the heaviest known substance.

Chemists believe that the elements differ in the construction of their atoms, as indicated above, for several reasons, the chief of which is that when the elements are arranged in such a scheme they are in the order of their increasing atomic weights, and their properties are a function of their position in the scheme.

The first clear apprehension that the elements are so related, that they form several series in which correspondingly placed members in these series exhibit similar properties, was due to Mendeléeff. The law has come to be known as the periodic law or, since any element has properties closely approximating the eighth one before or after it, if the elements are arranged on the basis of the atomic weights, it is also known as the law of octaves. The arrangement of the elements in the periodic scheme is shown in the table on pages 170 and 171. The explanation of their atomic structure in terms of protons and electrons is very recent, and is a tentative theory that may have to be much modified.

When elements unite to form a chemical compound, a positive element usually unites with a negative one. Thus positive sodium unites with negative chlorine to make common salt or sodium chloride. Positive elements do not unite with positive or negative with negative. Moreover, elements always unite in definite proportions by weight. That is one reason the atomic theory was adopted. If one atom of sodium always unites with one of chlorine to form a molecule of sodium chloride, then evidently they must unite in amounts proportional to the relative weights of the atoms. Sometimes, however, one atom of one element unites with two of another. Thus Mg unites with Cl to form $MgCl_2$, which means that one atom of magnesium has united with two atoms of chlorine to form one molecule of magnesium chloride. The number of bonds an atom of one element has, by which it attaches itself to the atom of another element, is designated the valence of the element. It will be

noted in the groups of elements under the periodic law that the elements in the first group, after the inert substances of group 0, like neon, argon, have a valence of one, those of the second two, the third three, and these are all positive. Substances in the fourth group may behave either as positives or negatives, and their valence is four. The fifth, sixth, and seventh groups have decreasing negative valences, three, two, one respectively, or they may rarely behave as positives, with valence of five, six,



a *b*

FIG. 67.—(*a*) Diagram of the sodium atom, with a group of protons at the center, two electrons indicated by dotted lines in the first sphere, eight in the next lying at the corners of a cube (suggested by lines) in the second sphere, and one electron of the next sphere. (*b*) Diagram of the fluorine atom.

seven respectively. Now this is all easily explicable on the basis of the structure of their atoms. Thus sodium has eleven protons and electrons arranged as shown in Figure 67*a*, while fluorine has nine arranged as in Figure 67*b*. Sodium has only one lonesome electron in its outer sphere. It needs seven more to fill up this sphere to satisfaction. Fluorine has its outer sphere full except for one electron. Now if fluorine takes this lonely electron in the outer sphere of sodium into its outer sphere to make up the eight, then this electron will jointly be a member of the sodium atom and of the fluorine atom. The two atoms are tied together and are united to form sodium fluoride.

ARRANGEMENT OF ELEMENTS ACCORDING TO THE PERIODIC LAW

Group 0	I	II	III	IV	V	VI	VII	VIII
He Helium 3.99	Li Lithium 6.94	Be Beryllium 9.1	B Boron 11.	C Carbon 12	N Nitrogen 14.01	O Oxygen 16	Fl Fluorine 19	
Ne Neon 20.2	Na Sodium 23.	Mg Magnesium 24.32	Al Aluminium 27.1	Si Silicon 28.3	P Phosphorus 31.04	S Sulphur 32.07	Cl Chlorine 35.46	
A Argon 39.88	K Potassium 39.1	Ca Calcium 40.07	Sc Scandium 44.1	Ti Titanium 48.1	Va Vanadium 51.	Cr Chromium 52	Mn Manganese 54.93	Iron Fe 55.84 Cobalt Co 58.97 Nickel Ni 58.68
	Cu Copper 63.57	Zn Zinc 65.37	Ga Gallium 69.9	Ge Germanium 72.5	As Arsenic 74.96	Se Selenium 79.2	Br Bromine 79.92	
Kr Krypton 82.9	Rb Rubidium 85.45	Sr Strontium 87.63	Yt Yttrium 89.	Zr Zirconium 90.6	Cb Columbium 93.5	Mo Molybdenum 96		Ruthenium Ru 101.7 Rhodium Rh 102.9 Palladium Pd 106.7

ARRANGEMENT OF ELEMENTS ACCORDING TO THE PERIODIC LAW—*Continued*

Group o	I	II	III	IV	V	VI	VII	VIII
	Ag Silver 107.88	Cd Cadmium 112.4	In Indium 114.8	Sn Tin 119.	Sb Antimony 120.2	Te Tellurium 127.	I Iodine 126.92	
X Xenon 130.2	Cs Caesium 132.81	Ba Barium 137.37	La Lanthanum 139.	Ce Cerium 140.25				
			Lu Lutecium 174.		Ta Tantalium 181.5	W Tungsten 184		Osmium Os 190.9 Iridium Ir 193.1 Platinum Pt 195.2
	Au Gold 197.	Hg Mercury 200.6	Tl Thallium 204.	Pb Lead 207.1	Bi Bismuth 208			
Nt Niton 222.4		Ra Radium 226.4		Th Thorium 232.4		U Uranium 238.2		

In a similar way magnesium has twelve electrons, two in the inner sphere, eight in the second sphere, and two in the third. Six more would be needed to supply this outer sphere, and it is difficult to get them. But oxygen has eight electrons, two in its inner sphere, six in its second sphere, and needs two more to satisfy this sphere. If an atom of magnesium and one of oxygen unite by using the two electrons in the third sphere of the magnesium atom to fill up the second sphere of the oxygen atom, we will have the substance known as the oxide of magnesium. Evidently it would take two atoms of fluorine to unite with one of magnesium to make magnesium fluoride whose formula is written, then, as $MgFl_2$.

But valences are not the only properties of the elements that seem to be sequentially arranged on the basis of this periodic law. The elements in any one column are very similar to each other in their physical properties and chemical behavior. Thus all the elements in the zero group or column are very inactive chemically. They may be regarded as having no tendency to combine with other substances—they have a valence of zero. The metals are more vigorously metallic in their characters as you go down the columns, and the non-metals are less vigorous in their non-metallic characters. Thus in column VII, fluorine is the most vigorous non-metal known, chlorine slightly less so, etc. Fluorine, chlorine, bromine, and iodine are so much alike they have been grouped together as the "halogens" for a long time. Color, density, and solubility of similar salts increase down each column. Thus fluorine is pale yellow, chlorine greenish yellow, bromine red, iodine purplish black. The melting-point of the elements decreases as you go down each column while the boiling-point increases.

The elements in the right column (VIII) do not fit well into this scheme, and chemists suspect that this periodic law is but a partial expression of the truth. In time we shall discover a better statement of it which will take in these apparent exceptions. It is, however, a working hypothesis and helps one to recall atomic

weight, valence, and other physical and chemical properties of the elements. It has been, too, a valuable aid in the discovery of new elements. For instance, when Mendeléeff first stated it the element scandium was unknown, as indeed were several others now known. He was able to predict the discovery of this element and to give its probable atomic weight, valence, and many of its physical and chemical properties. Chemists were therefore on the lookout for it, and it was only a few years after the prediction of its discovery before this was accomplished. The properties of the new element agreed remarkably well with the predictions.

One of the most startling discoveries of modern chemistry is that the elements which the old chemists thought were the simplest forms of matter and could not be resolved into still simpler things are capable of such resolution. The more complex ones like uranium and radium are giving off emanations by which they change to other so-called elements. Three things seem to be emitted from such decomposing substances: (1) what are known as alpha rays which seem to be streams of helium molecules, moving at about 18,000 miles per second; (2) beta rays or streams of electrons, moving with a very high velocity, about that of light, 186,000,000 miles per second; and (3) gamma rays or X-rays, a form of vibratory impulse. Bacquerel first discovered radioactive substances when he found that uranium would make a shadow picture on a photographic plate even through a protecting layer of black paper, and this in a perfectly dark place. This was in 1896. Professor and Madame Curie discovered polonium and radium, much more active substances, two years later. Now we know the uranium decomposes in time to form radium, which passes through several stages and gives rise to niton and this to polonium, which in turn by loss of these emanations becomes lead. The time consumed in these transitional changes varies greatly with the different substances. Thus, it takes some 5,000,000 years for half of a given mass of uranium to change to radium, but only about 136 days for polonium to change similarly to lead. These changes are as yet

beyond the control of man. They persist in going on under any and all conditions. He cannot stop them or start them.

Here is a possible source of energy that may some day be under man's control. If we could start an element to giving off this energy of decomposition and check it at will, it might put at our disposal the greatest source of energy available. We do use the emanations of radium now. When the alpha rays strike certain chemicals like the sulphate of zinc they make a visible splash of light. So we coat the hands of a watch with a paint in which there is such a chemical and a very tiny amount of a salt of radium, and the hands are then visible in the dark. Radium salts are used in the treatment of cancer and other pathological conditions. But they must be handled with extreme care for the radiant energy shot off causes the death and rapid decomposition of living tissue, making bad "burns," and they go through most any substance, penetrating the armor plate of a battleship as if there were nothing in their way. Lead seems to be relatively impervious to them.

The chief source of these radioactive substances is a mineral called carnotite. It is found in this country abundantly in Colorado and in less quantity elsewhere. Radium forms a very small part of it, so that it takes a trainload of the ore to make a thimbleful of the radium salt. Yet the energy given off by this amount is very great. It would make enough luminous paint to cover the state of Illinois.

These radioactive substances are not the only sources of streams of electrons and of X-rays. These were produced by electrical discharges through tubes from which the air or other gases had been largely exhausted (vacuum tubes) for some time before radioactive substances were discovered. The streams of electrons were known as cathode rays. The X-rays have been used in medical diagnosis for many years now. They penetrate flesh but are stopped in part by bone, metal, and other foreign substances so that it is possible to get pictures of broken or deformed bones, foreign substances such as bullets or pins that have lodged

in the tissue, and help the surgeon in determining the proper treatment (Fig. 68).

Fig. 68.—An X-ray photograph of a child's wrist

We have already been using in this and preceding chapters some chemical terms, and shall need to use others in later chapters. It is a very simple matter, however, to get in mind such elementary chemical concepts as are needed to understand the simple chemical processes treated in this book.

The difference between a physical change and a chemical change must be apparent from the discussion of burning in the preceding chapter. Heat a substance like solid ice and it changes to a liquid, and this in turn to steam, a gas. These, however, are merely three different physical states of water. So solid sulphur may be changed to liquid and solid iron to molten iron by heat. Heat sulphur still more in the air until it reaches its ignition point and it burns or unites with oxygen and forms a new substance, oxide of sulphur. So when iron burns in oxygen or rusts slowly in the moist air, a new substance is formed, an oxide of iron, with properties quite unlike iron.

Chemists have devised a sort of shorthand for writing out these reactions, and indicate the elements by the initial letter of their English or sometimes their Latin names. In case two or more elements begin with the same letter, it is necessary to use in such cases two letters from the name; thus C is carbon; Cl, chlorine; N, nitrogen; Na, sodium (Latin, *natrium*). Thus when sulphur burns the reaction is written:

$$S + O_2 = SO_2.$$

This means that one atom of sulphur unites with two of oxygen to form one molecule of sulphur dioxide. Such a statement to be an equation must, of course, have equal numbers of atoms of each substance on opposite sides of it.

Most chemical substances are classed as bases, acids, or salts. For our purpose we may define these simply. A base is a positive substance, like a metal, combined with OH, and is named a hydroxide. Thus KOH, $Ca(OH)_2$, are potassium hydroxide and calcium hydroxide respectively. The valence of the OH radical is one, of potassium one, but of calcium, two.

An acid is a negative or non-metallic substance combined with hydrogen; thus HCl is hydrochloric acid. When a base and acid are brought together, the positive component of the base usually combines with the negative element or radical of the acid to form a salt. The positive component thus takes the place of the hydrogen of the acid.

$$NaOH+HCl=NaCl+H_2O.$$

The NaCl is a salt and in this particular case it is the salt we call table salt.

The hydro- acids, like hydrochloric or chlorhydric, have no oxygen. So HBr is hydrobromic acid. Knowing the -ic acid, like $HClO_3$, chloric acid, you can always give the formulas of others of the same series, for the per.......ic acid, like $HClO_4$, perchloric acid, has one more atom of O than the -ic acid; the -ous acid, like $HClO_2$, or chlorous acid, has one less atom of O, and the hypo.......ous acid, like HClO, or hypochlorous acid, has two less than the -ic acid.

The salts formed from the acids are readily named:

Hydr- acids give -ide salts. NaCl is sodium chloride.

-ous acids give -ite salts. $NaClO_2$ is sodium chlorite.

-ic acids give -ate salts. $NaClO_3$ is sodium chlorate.

per.......ic acids give per.......ate salts. $NaClO_4$ is sodium perchlorate.

hypo.......ous acids give hypo.......ite salts. NaClO is sodium hypochlorite.

CHAPTER VIII

STEAM AND GASOLINE ENGINES

Soon shall thy arm, unconquered steam, afar
Drag the slow barge or drive the rapid car;
Or on wide, waving wings expanded, bear
The flying chariot through the fields of air.

—Erasmus Darwin (1731–1802).

No application of fire since man's early discovery of the methods to produce it at will has been more revolutionary in its effects on society than its application to the production and use of steam in the steam engine. Like so many other great inventions the steam engine is a cumulative product. Hero of Alexander one or two centuries before Christ devised a metal sphere with radiating elbow-shaped pipes about its equator which, when water was boiled in it, would revolve on its axis, propelled by the jets of steam that came out of the pipes which all opened in the plane of its equator and on the same side of their respective radii. But this was a curiosity and served no practical end. Branca, an Italian, early in the seventeenth century made a wheel rotate by jets of steam that struck paddles or blades along its circumference much as a water wheel is made to revolve by the water striking its paddles. He connected this wheel to a contrivance that he used for pulverizing drugs, so his steam engine was actually harnessed to do work. A Frenchman, Denis Papin (1647–1712), devised the piston and cylinder to operate by steam in 1690. Though born at Blois, he lived in London much of his life. He fitted a disk with an attached rod to a cylinder, closed at one end, the rod protruding at the open end. Steam was let into the closed end of the cylinder, and the disk was shoved along toward the open end. He suggested that by spraying water on to the closed end of the cylinder the steam

within would be condensed to water and a vacuum would tend to form. The pressure of the atmosphere on the disk would then drive it back toward the closed end. But it remained for an Englishman, Newcomen, to devise (1705) a means of making practical application of this idea.

Before this was accomplished, however, Thomas Savery devised a scheme for pumping water by the use of steam (Fig. 69). A pipe some 30 feet long dipped into the water at its lower end. At its upper end was a chamber that could be cut off from the pipe by a stopcock and that also had a vent pipe and a steam pipe both capable of being closed by stopcocks. Steam was let into the chamber, and the air let out while the cock to the water pipe was closed. When the chamber was full of steam, vent pipes and steam pipes were closed by the cocks. Then cold water was sprayed on the outside of the chamber until the steam inside condensed making a vacuum. The cock in the water pipe was then opened and the air pressure drove the water up the pipe into the chamber, when the water-pipe cock was closed and the vent pipe opened so the water could run out as steam was let in. So the process started all over again. This

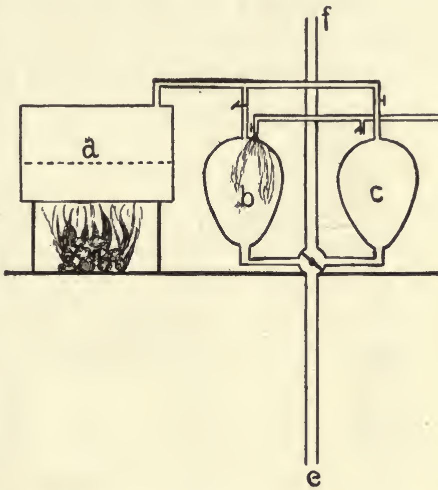


FIG. 69.—Diagram of Savery's improved steam pumping engine. Steam generated in *a* flows into *b* and fills it, after which the valve is closed and cold water from pipe *d* pours over the outside of *b*. Thus the steam condenses and water comes up through pipe *e*, which extends down into well or mine and fills *b*. Vessel *c* has been so filled, and now steam is entering it, forcing the water up pipe *f* toward the surface.

device worked slowly, for the chamber had to be heated by the flow of steam for some time, else the steam would condense as rapidly as it entered. The cocks were operated by hand by an attendant. Savery later improved this by adding a second chamber in order that while the steam was flowing into one it could be condensing in the other.

Newcomen built a vertical cylinder closed at its lower end and connected at the same end with a steam pipe from the

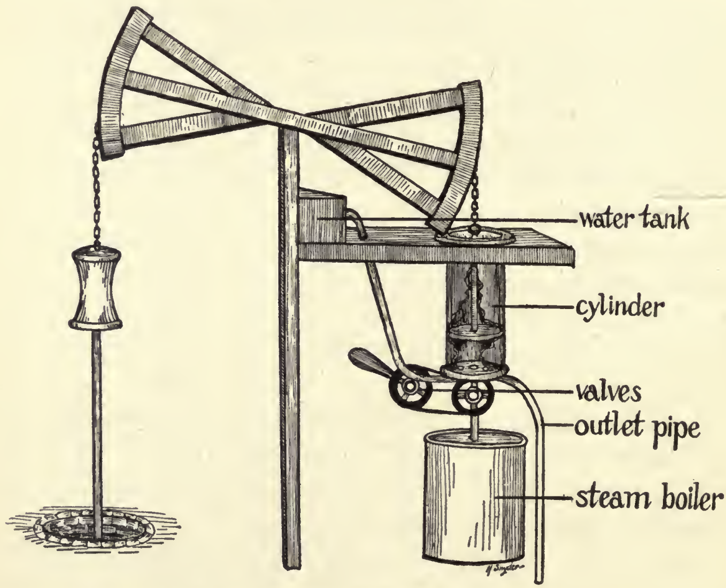


FIG. 70.—Diagram of Newcomen's engine

boiler (see Fig. 70). In this pipe there was a valve. Three other pipes also connected with this cylinder, each having a valve. One of these connected with a water tank so cold water could be sprayed into the cylinder, another was an outlet pipe for water, and the third an outlet pipe for air. The disk was connected by a chain to one end of a lever to the other end of which beyond the fulcrum there was attached another chain that fastened to a weight and to a pump. The attendant would open the air vent

and the steam inlet. The steam pressure used was slight, and it did not push the disk up. This was raised by the weight on the end of the lever, which weight also pushed the pump rod down. When the air was all expelled from the cylinder, and it was full of steam, the valve on the air vent was closed as also was the one on the steam inlet. Then the valve on the water pipe was opened and cold water let into the cylinder. This condensed the steam to water, which occupied only one two-thousandth of the space of the steam. Then air pressure forced the disk down, which brought down the arm of the lever to which it was attached and raised the other end with the attached weight and pump rod. The valves in the air pipe and in the water vent were now opened, the water let out of the cylinder, and the process was started over again. In spite of the fact that this engine was very crude and that the valves were operated by hand it was used to pump water out of the British mines, for it was an improvement on hand- or horse-power.

It remained for a resourceful Scotch lad, Humphrey Potter, who tended the valves on such a pumping engine at a mine, to rig ropes from the valve handles to moving parts of the engine so that they were opened and closed at the proper times. The engine thus became automatic. This arrangement was called a "scroggin"—a Scotch word, meaning "lazy."

A model of Newcomen's engine in the museum of the University of Glasgow was turned over for repair in the year 1763 to James Watt, an instrument maker connected with the university. This led him to think of various means of improving this crude device and to the invention of a real steam engine, one in which steam alone furnished the propulsive power. Watt called his engine a "fire engine" (Fig. 71, p. 182). He saw that the expansive power of the steam itself could be used to force the piston head first one way and then the other in the cylinder. He built the cylinder of his engine closed at both ends with the piston rod coming out at one end through a steam-tight packing of greased tow. He arranged the valves in a way to let steam in

at one end of the cylinder while a valve at the other end was open to let out the exhaust steam. Then these valves closed and others opened to reverse the process. A second very important improvement he thought out was the addition of condensing

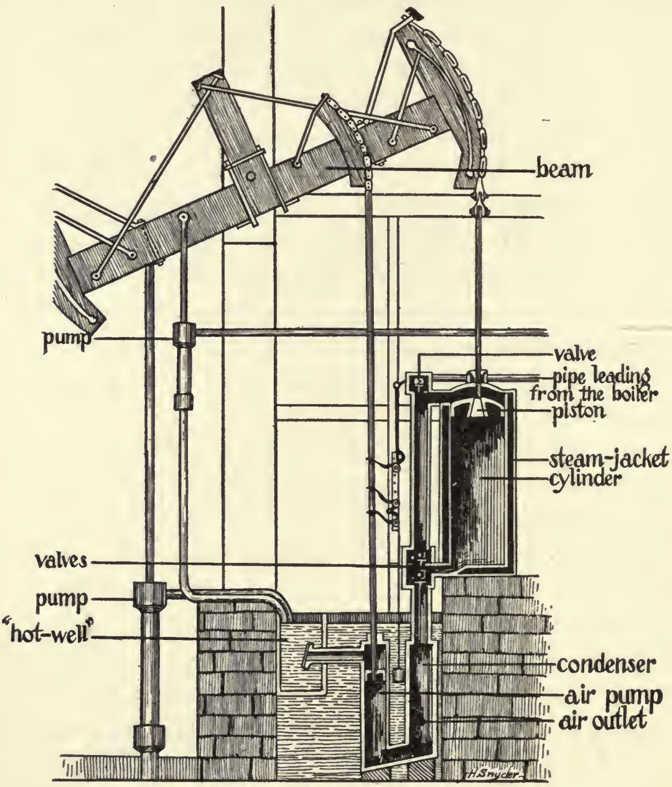


FIG.—71. Diagram of Watt's steam engine

chambers. Instead of condensing the steam in the cylinder itself the exhaust steam went to a separate chamber where it was cooled by water. Since this chamber was a partial vacuum, the exhaust steam rushed out of the cylinder into it the moment the valve was opened so the pressure in one end of the cylinder was very slight while that at the other was high because live steam

was entering it. This made the thrust of the piston very powerful. He also incased the cylinder in a larger one in order to keep steam in the space between them. This kept the inner cylinder hot so the steam entering it would not condense in part and thus lose its power. In the fourth place he attached the free end of the piston rod to a heavy flywheel in order to make it whirl round. The stroke of the piston is a back-and-forth stroke, and at each end of the stroke there is a moment when it stands still and is exerting no pressure to make the machine go. The momentum of the revolving flywheel carries the piston past this dead point and makes the engine run smoothly rather than jerkily. The governor was the fifth major improvement that Watt devised. When an engine is working, the load on it is necessarily a variable one. Thus it is more work to lift the water in a mine pump than it is merely to drop the pump plunger for the next stroke. The engine thus tends to slow down when hard work is being done and to race when the load is lessened. Watt's governor automatically partially closed the valve on the steam inlet pipe when the engine speeded up and opened it wider when it slowed down. The method of operation will be described below. It is evident from what has been said here that Watt was the real inventor of the steam engine. He did so much more than his predecessors toward making it a practical machine that he deserves the lion's share of the credit.

He not only largely created the steam engine, but he devised the measure which we still use to express its work capacity. Since the "fire engine" was taking the place of the horse as a means of doing work, it was natural that its ability to work should be expressed in horse-power. Watt concluded that a good horse could draw 1,000 pounds up a hill 33 feet high in one minute and so he adopted this as the unit of measure to indicate the power of an engine. He rather overestimated the power of a horse, but we use his horse-power today to measure the work capacity of an engine. A fifty-horse-power engine is one that could raise 50,000 pounds 33 feet in one minute.

The general method of operation of the modern steam engine is very much the same as that of Watt's fire engine, though very many improvements in details have been made in it. The boiler is commonly what is known as the tubular type in which the draft carries the heat from the fire box up between numerous pipes or tubes containing the water that is to be turned to steam. These tubes present a much larger heating surface than the old type of kettle-like boiler, and steam can be made much more rapidly. The modern boiler is so well made that it stands high pressures, and the steam is sent to the cylinders with a pressure of several hundred pounds to the square inch.

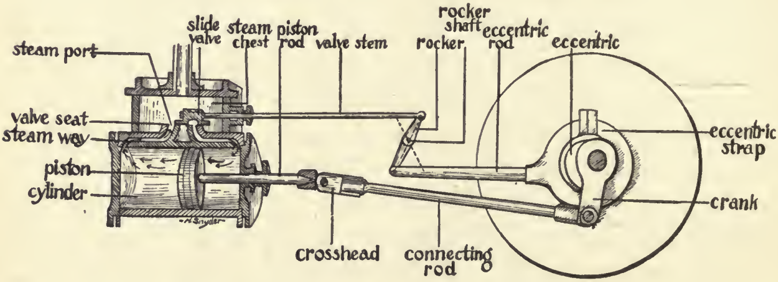


FIG. 72.—Diagram of a modern steam engine

When the engineer opens the throttle of the engine it lets steam from the boiler into the steam chest that lies next to the cylinder. Sliding valves between steam chest and cylinder let steam first into one end and then into the other, at the same time others open to let out the exhaust steam. These valves are operated by a rod attached to the eccentric or similar device. The method of operation of this portion of the engine should be plain from the study of the accompanying diagram (Fig. 72). The exhaust steam from the high-pressure cylinder may be discharged directly into the air through the smokestack or it may go to a condensing chamber in the so-called condensing engine or it may enter another steam chest and cylinder that works at less pressure before going to the condenser, for the work power of the steam in high-pressure engines is not taken out of it entirely

in the first cylinder. These latter engines are called double-expansion or, if three cylinders receive the steam one after another, triple-expansion engines.

The free end of the piston rod is attached by a movable joint to the crank shaft—a shaft with a right-angled bend to it like the crank for an automobile or that on a grindstone or coffee mill—so that the back-and-forth motion of the piston rod is transformed to a rotary motion of the shaft and its attached flywheel.

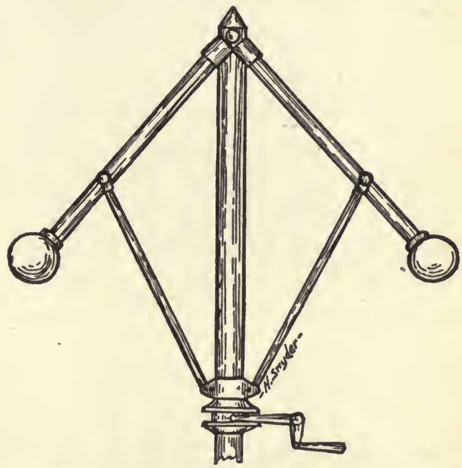


FIG. 73.—Diagram of the governor of a steam engine.

The governor on many engines now is very like the one devised by Watt. A solid vertical rod has firmly fixed near its lower end a wheel which by teeth or belt is geared to a rotating shaft of the engine and the rod thus rotates rapidly about its longitudinal axis (Fig. 73). Two arms are jointed by one end to opposite sides of the upper end of this rod. Near the lower free end of each arm there is fixed a heavy metal ball. A rod is attached near the end of each free arm and runs thence to a collar that encircles the rod several inches below the level of the balls. The rods attach to this collar by a movable joint. This collar fits into another one just below it so that the lower one must move up and down with it but need not revolve with it. As the vertical rod rotates, the balls attached to the arms whirl about and stand away from the rod on account of centrifugal force. The faster the rotation, the farther away they move. As they move out the rods attached just above them pull the collar up on the vertical rod. To the second collar a rod attaches that runs to the valve

in the steam intake, which is thereby closed as the collar rises: When the engine slows down, the balls move in closer to the vertical rod, the collar is pushed down, and the valve is opened. In this way the engine is made to run at a nearly uniform speed.

The exhaust steam is made to heat the water before it is sent into the boiler until it is almost ready to boil. Since the pressure in the boiler is great the water has to be driven in by force. An injector is generally used for this purpose.

The stationary engine came rapidly into use late in the eighteenth and early in the nineteenth century, for running machines that were being invented to aid man in his labors. Up to this time manufacture had been largely a household process. The shoemaker made the shoes at home and his wife and children all helped. Wool was combed, corded, spun into thread, dyed, and woven into cloth, all in the home. The spinning-wheel and hand-power loom were part of the necessary equipment in the home of the weaver and everybody worked, including father. On the farm everything was done by hand (Figs. 74, 75). In town and country it took the combined labor of all the family to pay for the necessary food, clothing, and shelter. Even the little children found some tasks. But the steam engine and power machinery began to shift manufacture from the home to the factory. Workmen saw machines doing the work of 100 hand operatives (Fig. 76, p. 188). They were afraid the factories were going to deprive them of the chance to work, for children and women could tend machines. Mobs tried to burn the mills and destroy the machines and in many cases they succeeded. But what appeared temporarily as a menace to labor proved a great blessing, for steam power and machinery increased production. A single steam engine can do the work of 10,000 men, and do it ceaselessly and tirelessly.

The more expeditiously man can obtain raw materials, like iron, coal, wood, grain, and manufacture them into the things he needs, the more rapidly he accumulates wealth. William E. Gladstone once estimated that the wealth of the world increased

FIG. 74.—Harvesting grain by hand

FIG. 75.—Reaping and binding grain by machine power

as much in the first fifty years of the nineteenth century, due largely to the use of steam, as it had in the preceding fifty centuries. It doubled again in the next twenty-five years, and was doubling even more rapidly before we learned to spend with such prodigality in the Great War.

Because of this great increase of wealth children, at least in their early years, were released from the slavery of production, and were free to go to school. The laborer could begin to have

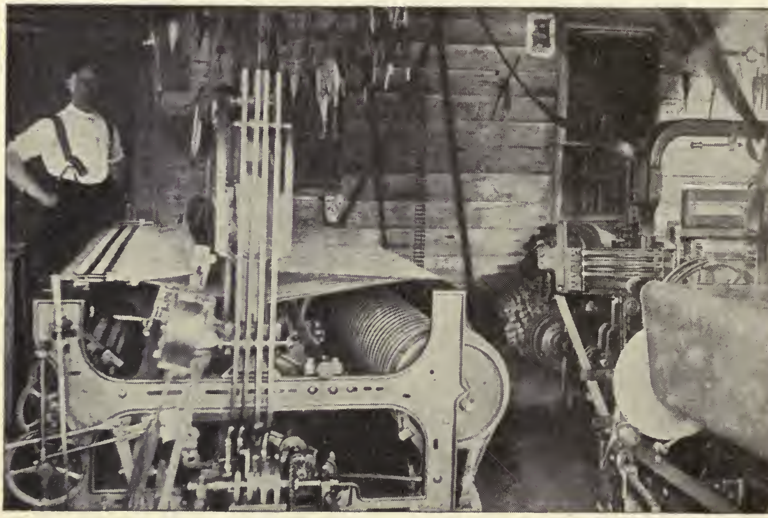


FIG. 76.—An early power loom

some leisure. The working day was cut to twelve, then ten, then eight hours. Women were freed to devote themselves to home duties rather than labor in field or factory. Public schools began to serve the children of the common people about the time this industrial and social revolution was coming on, due to power production. They appeared somewhat earlier in this country of ours whose virgin resources made the production of wealth relatively easy from the first. Still in 1800 the average child in this country was getting only eighty-two days' schooling, while in 1900 this had increased to 1,040 days. The age of com-

pulsory school attendance has constantly advanced until it stands at seventeen years in some states, sixteen in not a few, and fourteen pretty generally. The first part of the nineteenth century saw the public graded schools gradually fill up so that since 1870 there has been no increase of the percentage of the population that is attending them. But there has been a marked increase in the attendance in the public high schools. Since 1900 high-school attendance has increased seven fold, college and university attendance twelve fold, while the increase in the general population has not even doubled. It might be a fit tribute if the school children of the world should erect monuments to Papin, Newcomen, and Watt, inventors of the steam engine that has made possible their commercial freedom, their public schools, and yet perhaps the boys and girls themselves, happy in their increased opportunities, are their best imperishable monuments.

While the stationary engine was rapidly increasing production, attempts were being made to use steam power for distribution also. The first practical steamboat, also commercially successful, was built by Symington and put to service on the Forth and Clyde Canal in the year 1802. Fulton's famous steamer, the "Clermont," laboriously made its way up the Hudson River first in 1807, and plied regularly after that between New York and Albany. The "Clermont" was not Fulton's first steamboat, for while in France in 1803 he had built and operated a small one on the river Seine.

The locomotive appeared in 1804 but it was a very primitive affair. It ran on a road of flat iron plates with the outer edges turned up so the engine would not run off. The toothed drive wheels played into toothed strips on the roadbed. It was used for hauling cars of coal at the mines. The rolled malleable iron rail with the flange on the wheels of engine and car came into use first about 1820. It was considerably later, however, before smooth rails and smooth-faced wheels were used or even tried, for it was so perfectly evident that the smooth wheel would not grip a smooth rail enough to give traction that no one ever

thought of trying them. The carriages on many early railroads were pulled by horses, and they were merely stage coaches fitted for riding the rails. When in 1828 the Liverpool and Manchester Railway was under construction, there was prolonged discussion among its directors as to whether horses or engines should be used to draw the carriages. It was the influence of Mr. George Stephenson that finally decided the matter in favor of steam power. His engine, the "Rocket," took the prize offered by the directors. It weighed $4\frac{1}{2}$ tons, and drew a train of coaches weighing nearly 13 tons at an average speed of 14 miles an hour

FIG. 77.—The first railroad train in the United States

and a maximum of 29. A serious article in that most serious English periodical, the *Quarterly Review*, for March, 1825, expresses the hope "that Parliament will in all railways it may sanction limit the speed to 8 or 9 miles per hour which is as great as can be ventured on with safety." Smile's *Life of George Stephenson* is well worth reading to obtain some notion of the difficulties and opposition the early railroads encountered and overcame. The first railroad train in the United States made its maiden trip in 1831 (Fig. 77).

As early as 1770 a Frenchman, Cugnot by name, built and operated a small wagon with three wheels that was propelled by a steam engine mounted on it. This, I believe, was the first

motor car. Constant improvements were made in such steam-motor cars and their engines and by the middle of the nineteenth century steam-motor busses were in use to some extent, and the steam-motor car while still a novelty gave promise of general use. Such promise would undoubtedly have been realized had not the gasoline engine been rapidly developed. In 1900 there were about 700 automobiles in the United States, all of which were steam cars except a few imported ones. In 1910, 400,000 cars were in use here and very few were steam-driven—nearly all makers having adopted the gasoline engine.

The gasoline engine has many advantages over the steam engine, especially where a portable power plant is required. It develops a greater horse-power in proportion to its weight than does the steam engine. It wastes less of the power that is developed than does the steam engine. In the latter there is a great loss of energy through radiation of heat, by friction, and in other ways, so that only from 6 to 12 per cent of the energy generated by burning the coal is actually delivered as mechanical energy to do the work required. A good gasoline engine delivers from 20 to 40 per cent of the energy of the gasoline.

Gasoline is a highly volatile liquid composed largely of carbon and hydrogen. When it burns or unites chemically with oxygen it gives rise to carbon dioxide (or carbon monoxide, a very poisonous gas, if the oxygen supply is limited) and water vapor or steam. These gases are produced in large volume from a very small amount of gasoline so that, if the latter is mixed well with air so it will burn quickly and thoroughly and the mixture is fired in a confined space, an explosion occurs just as happens when gunpowder is set off in a small space. It is the elasticity of these confined gases that exerts the pressure on the piston head in the cylinders. In general, the plan of operation of the gas engine is similar to that of the steam engine; the piston, however, is driven only in one direction by the force of the explosion. It is forced back again by the action of other cylinders that fire later and are coupled up with the same crank shaft.

The gasoline engine consists essentially of at least two *cylinders* in which the gas explosions occur alternately, the *pistons* which connect by their rods with the crank shaft that bears the flywheel, the *spark plugs*, one in the end of each cylinder where occurs the electric spark that fires the gas, the *carburetor* in which the gasoline vapor is mixed with air before it is drawn into the cylinders, and a *storage battery*, or else a *magneto*, which supplies the electric current to the spark plugs. There are many accessory parts (Fig. 78).

The gasoline engine is usually at least a two-cylinder engine, the cylinders firing alternately, and in most automobile engines the cylinders are still more numerous, four, six, or twelve. Then they work in groups, the explosion and out stroke (or power stroke) occurring in part of them, while in others the piston head is moving in to compress the gases (compression stroke), in still others to drive out the gases after burning (exhaust stroke). The crank shaft to which one end of each piston rod attaches by a movable joint is a forged and accurately turned steel shaft with as many right-angled bends in it, like squares with one side open, as there are piston rods. Each piston rod fastens loosely to one bend, and helps to rotate the crank shaft as hand and arm rotate the crank on a coffee mill. In a two-cylinder engine the two bends are in the same plane but face in opposite directions. In a four-cylinder engine the pairs of bends are similarly placed, one pair facing one way, the other in the opposite direction. In the six-cylinder engine there are three pairs of bends that lie in three planes that are 120° apart. By such an arrangement the crank shaft is rotated by a succession of thrusts of the piston rods rather than having them all push at once, and so the engine runs smoothly.

There are really four phases to a complete cycle in any cylinder. Beginning with the explosion: (1) the piston head (and rod) moves out, then (2) it moves in to expel the gases formed by the explosion, (3) it moves out to draw in the new charge of gasoline vapor mixed with air, and finally (4) it

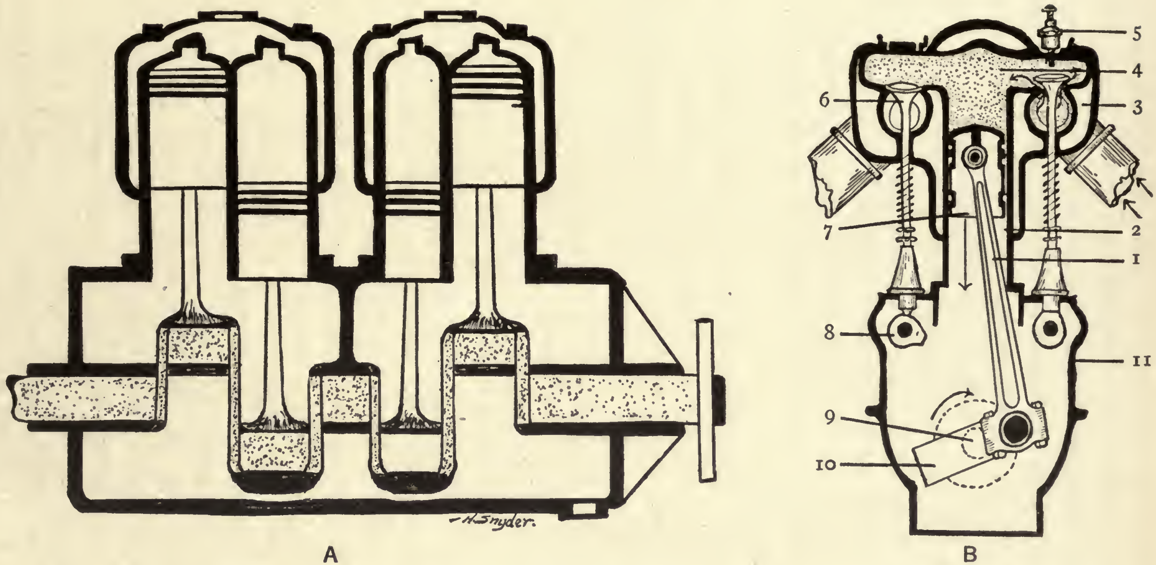


FIG. 78.—Two diagrams of a gasoline engine. *A*—Cross-section of engine. *B*—Cross-section of cylinder and crank shaft at right angles to diagram *A*. 1 = piston rod; 2 = cylinder; 3 = water space; 4 = gas mixture; 5 = spark plug; 6 = valve; 7 = piston head; 8 = cam; 9 = crank shaft; 10 = crank; 11 = jacket.

moves in to compress the mixture after which the explosion occurs and the cycle begins over again.

Evidently there must be valves arranged so as to open and let out the burned gas, others to let in the fresh mixture of air and gasoline, and these must open and close at just the right times. These valves are usually opened by rods that are raised and lowered by eccentrically placed disks called cams revolving on a cam shaft (see Fig. 78*B*). The valves are closed by springs. In some engines the valves operate by means of a rotating sleeve that fits inside the cylinder with holes in the sleeve and in the cylinders that coincide when gases are to enter or leave, but are closed at other times.

The continued burning of gasoline in the cylinders would naturally keep them very hot. They are cooled either by a draft of air or more often by a jacket of water that is forced to circulate in the spaces about them. This water is kept cool by circulating also in the radiator, a honeycomb metal device with water in the hollow comb and air drawn through its holes by a fan operated by a belt or chain drive to the crank shaft.

The carburetor is very variable in different makes (one is diagrammed here, Fig. 79), but its purpose is the same in all, namely, to saturate partially the air with gasoline vapor before it is drawn into the cylinders. Gasoline is either carried to the carburetor by gravity from the gasoline tank or pumped up to it. Usually there is a "choke" attached to the carburetor, a sort of damper which regulates the air intake. When it is wide open, the air goes in rapidly, and is not as completely filled with gasoline vapor as it is when it is closed so the air enters slowly. In the former case the mixture is said to be lean, in the latter rich. In starting the engine a rich mixture is used. After it has been running a short time and the cylinders get heated, the mixture becomes hot also, and will fire even if it is lean. When one "steps on the gas," a throttle in the pipe between the cylinder and the carburetor is opened, thus allowing more of the mixture to flow in and make the explosions more

forceful, as the car speeds up. This same valve may be operated by a lever on the steering wheel.

The mixture of gas and air in the cylinder is ignited by an electric spark. A spark plug is set into the end of the cylinder or just at one side of the end. This bears two metallic points at its inner end between which an electric spark passes when the mixture is properly compressed, and since the mixture is all around the spark the latter ignites it. The electricity is furnished either by the storage battery or by a magneto, an electric

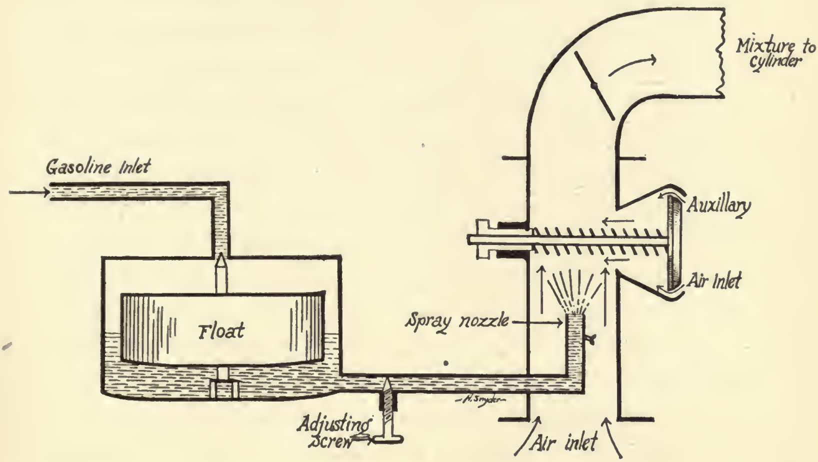


FIG. 79.—Diagram of a carburetor

generator, that is run by a belt or cogwheels attaching to the crank shaft or other moving part. It takes a high-voltage alternating current to send this spark across the gap, a much higher voltage than the battery furnishes, so the current is sent through an induction coil to change the low-voltage direct current of the battery to a high-voltage alternating current. This will be better understood after reading the chapters on electricity (p. 254). The ammeter on the instrument board shows the strength of the current that is being furnished by the battery. A dynamo, power to run which comes from an axle or from the crank shaft,

sends a current to the battery to replace the electricity used constantly at the spark plugs and in the lights.

The current from the induction coil to the spark plugs must also pass through the distributor and the timer. The distributor sends the current first to one cylinder then to another and so on, so they will be fired in the proper order. This is usually not the order in which the cylinders stand in their row. The firing order in a four-cylinder engine may be cylinder one, then three, then four, and, finally, two, rather than one, two, three, four, for the vibration of the engine is usually less when the order is not in the regular succession. The timer determines the exact moment at which the spark fires the mixture with reference to the position of the piston. When the engine is running slowly, firing can come at the moment of greatest compression as the piston head has reached the top of its stroke and is just about to begin the descent. But when the engine is running rapidly, the spark must come slightly sooner else the piston head will be well on its down stroke before the gases will develop their maximum pressure. The timer in most machines is now automatic in this adjustment, but a lever is put on the steering wheel to advance or retard the spark when speeds are very extreme.

When the valves are opened to let the gases out of the cylinders after the gasoline is burned, they are still under high pressure, and if discharged directly into the air they would come out with a noise like that of a pistol shot. They are therefore discharged through a muffler, a long tube of increasing diameter with numerous incomplete cross-partitions. The gases go into a succession of constantly enlarging chambers, and thus expand gradually instead of suddenly. When the muffler is not in use the "cut out" is said to be "open," and the exhaust is noisy.

As explained, the piston rods are so attached to the crank shaft as to make it turn around. On the rear end of this crank shaft is a heavy flywheel which helps to keep the engine running smoothly and which also serves to transmit the engine's power to the rear wheels of the car. Through a device known as a clutch

it transmits its rotation to a secondary shaft on which are cogwheels of various sizes (Fig. 80). The operation of the clutch may be illustrated thus: Set the eraser of your pencil down on a card or sheet of paper on a smooth table, then give the pencil a rotary motion between your fingers. If the rubber is at the same time pressed on to the card, the latter will also turn around. One face of the solid fly-wheel has pressed against it a disk on the end of the secondary shaft, and so this shaft turns with the wheel. The pressure is maintained by a spring except when the clutch pedal is in. In most machines now, the clutch is of a multiple-disk variety in which several disks on the secondary shaft engage corresponding projecting plates on the flywheel.

By means of the gear-shift lever, cog-wheels of several sizes

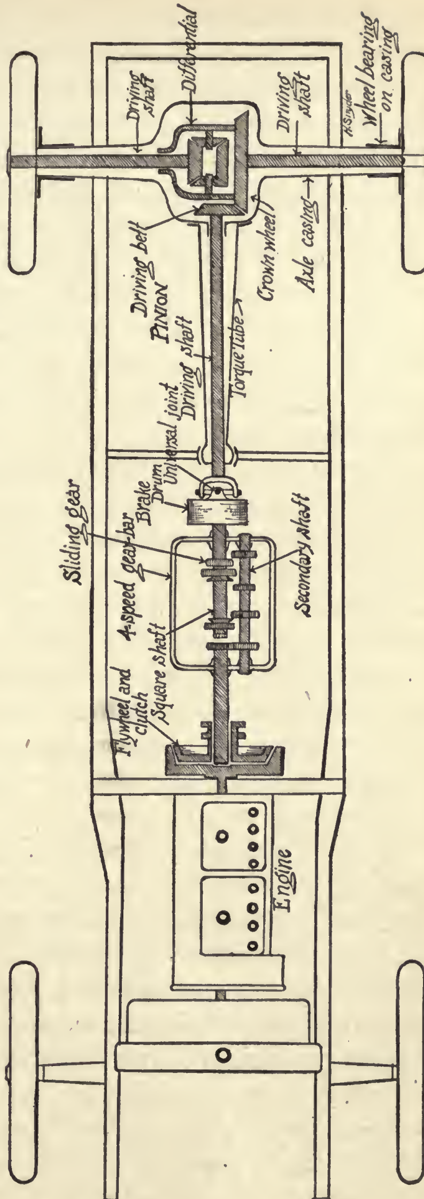


FIG. 80.—Diagram of an automobile chassis showing the gear shift

on the transmission shaft may one at a time be brought into such position that their teeth interlock with the teeth on the cogwheels on the secondary shaft, and the transmission shaft is set rotating. Through a flexible joint it conveys the rotary motion to the rear wheels. If a large cogwheel on the transmission shaft is geared into a small one on the secondary shaft, it will take several turns of the latter to turn the former once and the transmission shaft and the rear wheels will turn slowly. If, on the contrary, a small wheel on the transmission shaft is geared into a large one on the secondary shaft, then the rear wheels will turn rapidly and the car will run fast. When the gear shaft is set "at neutral," no wheel on the transmission shaft is playing into the wheel on the secondary shaft.

There are many bearings in an automobile engine that need constant lubrication. Thus the crank shaft may make 1,000 or more revolutions a minute when the machine is running rapidly. This would create much friction unless the bearings were well oiled. The oiling is partly accomplished by having below the engine a pan of oil, which splashes up and keeps the moving parts lubricated. In addition an oil pump forces oil along small tubes bored in the center of the shafting and out of tiny holes in the bearings. Frequently an oil gauge is put on the instrument board connected with this system to show that the oil is moving properly.

An electric motor is connected with the storage battery so that when a current is sent into it, it turns a cogwheel that plays into cogs on the circumference of the flywheel and the engine is "turned over" to start it. You step on the starter or press a button to accomplish this. Just as soon as the cylinders have drawn gas and air into themselves and the mixture is set off by the sparking of the plugs, the engine begins to run of itself, the starter is disconnected, and the electric motor stopped. Sometimes the engine is turned over by hand by means of a crank temporarily fitted on to the forward end of the crank shaft. But the self-starter is in quite general use.

CHAPTER IX

DISCOVERIES IN MAGNETISM AND ELECTRICITY

He snatched the lightning from the heaven and scepters from tyrants.—Inscription on Franklin's Bust.

In these days when streets and houses are lighted by electric lamps, when the telephone is a necessity and the telegraph a commonplace, when the electric motor furnishes power, not only for the shop, but for the washing machine and sewing machine in the home, when old and young alike are amusing themselves with radio concerts and lectures, it is hard to realize that all these electrical contrivances are recent inventions which people not yet old saw introduced. To most of us they are still mysterious. What child has not wondered how they make the electric current that produces the light as he presses the button, or how the telephone can reproduce so clearly the voice of his chum, or how that very modern marvel, the radio, can send messages without even the semblance of connecting wires? What boy has not stood lost in wonder at the window of the telegraph office and watched with fascination the messages sent and received, or envied the electrician at the power-house who seemed to know all about the great dynamo whose smooth, whirring speed sends out the current? Even our playthings now are electrical, and it is not difficult for the child to repeat experiments that once were great discoveries, and gain from them in his play a knowledge of the principles that underlie these magnetic and electrical appliances that have so largely helped to revolutionize the modern commercial world.

Very ancient peoples knew there was a kind of a stone to be found that attracts bits of iron. It was called the lodestone, or magnet, because it was found quite commonly near Magnesia,

a city in Ionia, a province of Greece. This lodestone is one of the ores of iron, an oxide of iron, known as magnetite. They knew also that a piece of iron rubbed on such a stone became a magnet. We know now other and better ways of making a magnet, as will appear below.

In the city of Naples, Italy, is a monument to Flavio Gioja, a man who lived in the city of Amalfi, and the legend on the monument ascribes to him the discovery of the compass in the year 1302. This is undoubtedly an error, for Peter de Maricourt, a Frenchman, also known as Peregrinus, had devised a compass with pivoted needle and graduated scale as early as 1269, and mention is made of it in cruder form nearly a hundred years earlier. This primitive compass consisted of a magnetized needle that floated on a cork in a basin of water. Gioja did make improvements in the compass. At that time there was no Italy. Amalfi, once an independent republic, then belonged to the kingdom of Naples, whose ruler was of the royal family of France. So Gioja marked the north-pointing end of his compass needle with the fleur-de-lis, symbol of the iris, the flower of France that appears on her coat-of-arms. It still is usually so marked.

Amalfi was once a great center of commerce whose ships ruled the Mediterranean and brought her great wealth. Now the stone wharves where her ships unloaded are lying below the sea, due to a submergence of that portion of the coast. Her prestige is gone. Still she will long be remembered, for the compass which came from her in its improved form was a boon to commerce. By it a vessel finds its way from port to port even when clouds obscure the stars and the mariner has no guide but the little steadfast needle.

The end of the magnet that points north when the magnet is freely suspended is called the north pole and the other end the south pole. When two such magnets are brought together end to end, they repel each other if the poles are alike, but attract if they are unlike. This fact may readily be discovered by any

child who has a pair of magnets to play with, and to make a discovery like this for one's self is really thrilling.

If a nail or other bit of iron is brought near the end of a bar magnet, it leaps toward it and is held firmly by it (Fig. 81). When a second nail touches the end of the first, it is held to the first, for the nail in contact with the magnet has also become a magnet. So quite a chain of nails may be held by the bar magnet, and a great cluster of tacks or iron filings will cling to it and to each other. If you make a little paper or wooden boat and put a nail in it, the magnet will draw it about when it floats in a basin of water even when the magnet is quite a distance away, for this magnetic force works through paper, wood, glass, or other substances.

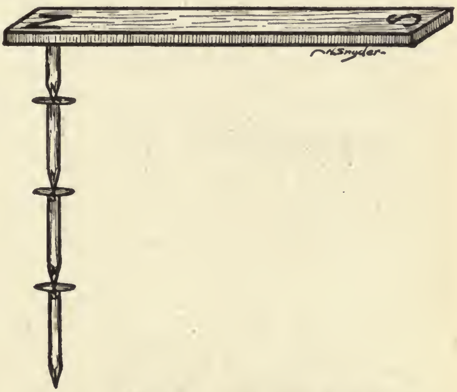


FIG. 81.—Magnet holding a string of nails

If you lay a bar magnet down on a table with a sheet of cardboard or stiff paper over it, then sprinkle iron filings on the paper and gently tap the latter, the filings arrange themselves in a strange pattern (Fig. 82). They seem to lie along lines of force that radiate from one pole and turn around to converge at the other. If a sheet of blue-print paper is used in place of ordinary paper and the experiment is set in bright sunshine, when the filings have arranged themselves, the peculiar design will leave its shadow on the paper permanently. After the paper has stood until it begins to assume a bronzed tint, take it out of the sun, shake off the iron filings, and wash it in water thoroughly; then pin it up to dry. The design will appear white on a blue ground.

If a compass is set on the sheet of cardboard in the foregoing experiment, its needle will assume a position parallel with the

line of force that runs through it. This and other bits of evidence make scientists think that the earth is a great magnet with such lines of force running from pole to pole, so making the compass needle point northward. The magnetic poles, however, do not quite coincide with the geographic poles, so the compass needle does not point exactly to the north in most places. This deviation must be taken into consideration in setting a ship's course.

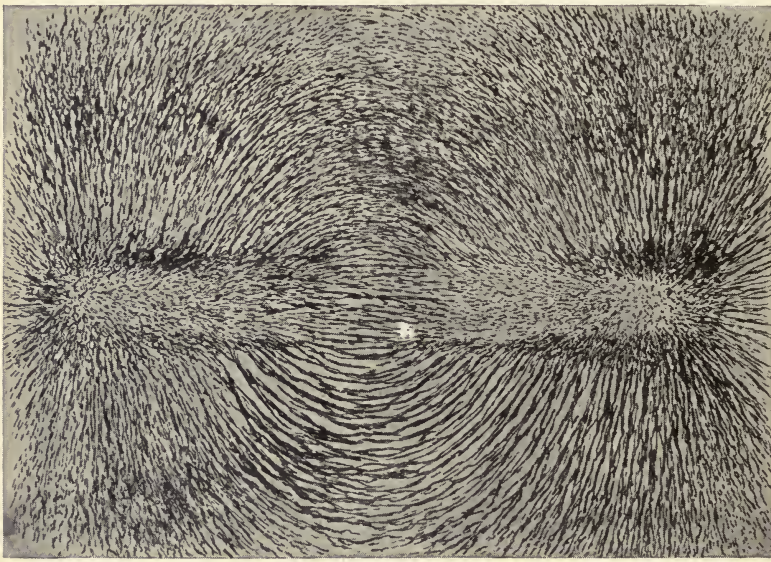


FIG. 82.—Pattern of iron filings on a sheet of paper over a magnet

Possibly it is currents of electricity that course around the earth that make of the earth a magnet, just as we shall see it is possible to make a bar of iron into a magnet by sending an electric current through a wire coiled about it. But we must know something of electricity to appreciate this.

The ancients knew a little about electricity as well as about magnetism. They knew that if one rubs a piece of resinous substance, like amber, on cloth it will then attract light substances like bits of straw or dry pith. Gilbert, an English physician,

discovered that sulphur, sealing wax, alum, and many other substances behave in the same way when rubbed on cloth, and he published the first book about electric phenomena in 1600 A.D., though he called such phenomena magnetic not electric. There were thus many centuries during which nothing had been added to the simple knowledge of the ancients in regard to electricity. Then Otto Guericke, the man who made the first air pump and who tried the famous experiment with the hemispheres at Magdeburg (p. 111) to show how great is air pressure, discovered that electrified bodies may repel each other as well as attract. You can easily repeat his experiment. Hang up a pith ball or even a small round wad of tissue paper by a fine silk thread. The results will be more emphatic if the ball is covered with lightweight tin foil. Rub a glass rod or tube or a stick of sealing wax with a piece of silk or wool cloth and bring the rod near the ball. The ball promptly flies to the rod, adheres to it a few moments until its surface also is charged with electricity like that on the rod, and then it flies away from the rod. Rub again and present the rod to the ball, and now the ball is strongly repelled, for both are charged with the same kind of electricity. So Guericke said that a body charged with electricity draws to itself one that is not charged but repels it the moment it is also charged.

It was not until 1762 that DuFay discovered that there were apparently two kinds of electricity. When the ball is charged with electricity from the glass rod rubbed with silk, it is repelled by the glass rod, but if there be then presented to it a stick of sealing wax rubbed with silk it is strongly attracted. Furthermore, while it is repelled by the glass it is attracted to the surface of the silk that has been used to rub the glass. So DuFay said there are two sorts of electricity. Unlike kinds of electricity attract each other but like sorts repel. An amusing method of demonstrating the attraction and repulsion is as follows. Cut some tiny dolls or figures of animals a half-inch high out of tissue paper. Scatter these on a table so they will lie under a good-

sized piece of window glass supported between the leaves of two books so it is a little over a half-inch above the table. Rub the upper surface of the glass briskly with a piece of silk or wool cloth. Shortly the figures will dance as they fly up to the glass on which the electricity is developed, become charged with it, so fly away again to the table to which the charge is discharged, when the process is repeated.

This electricity that is developed by friction is known as frictional electricity. You have probably heard it crackle while combing your hair when it is dry and cool, or have felt and seen the spark fly when, after shuffling across the rug, you have presented your finger to some metal object like the radiator or water pipe. The two kinds that are developed, one on glass when it is rubbed with silk, the other on amber or sealing wax when it is so rubbed, were at first called vitreous (glassy) electricity and resinous electricity. But later they were designated positive and negative respectively, for when they come together they neutralize each other and no charge is apparent. They appear to be present in equal quantities in such substances and are merely separated by rubbing.

In 1749 Benjamin Franklin performed his famous kite experiment. By this time men knew how to make quite powerful frictional electric machines, so he knew from his work with these that the electric spark has a zigzag course, crackles as it appears, may set things on fire, can even kill small animals, and discharges most readily from pointed conductors. He knew that in many respects lightning behaved similarly, and so he surmised that lightning was electricity discharging from cloud to cloud or from a cloud to the earth, and that buildings might be protected from lightning stroke by setting in the ground near them tall, pointed, metal rods in order that the electric discharge would pass through them instead of through the buildings. This seemed very absurd even to the scientists of his day, and his suggestion was received only with amusement. But Franklin was not to be easily discouraged. He decided to try an experi-

ment to test his theory. He told no one about it but his son, who was to be a witness. In a thunder shower he sent up a silk-covered kite. At first nothing happened, but as soon as kite and string were sufficiently wet to serve as good conductors, the current came down the string and jumped, in a succession of sparks, from a key that Franklin had tied to it, to any good conductor presented to it. Franklin was holding the kite string with a piece of dry silk which is not a good conductor so that the current would not pass into his body, for that might have been dangerous.

When the tiny particles of water are carried up, as warm air rises from the earth, they rub against the surrounding air, and so by friction generate electricity. Such electricity is carried on the surface of the object that is charged with it. These tiny electrified particles merge to form larger and larger drops that make a visible group of them, which we call a cloud. Finally, they may become so large and heavy that they can no longer float in the air and they fall as rain. As two of these particles fuse, the surface of the resultant droplet is not as great as their combined surfaces, for surfaces increase only as the square of the radius, while volumes increase as its cube. Surface does not increase as rapidly, therefore, as volume. So the electricity on the drops, growing constantly larger, becomes crowded. The cloud becomes overcharged and finally much of its electricity leaps toward another part of the cloud, to another cloud that happens to have a charge of the opposite kind, or toward some portion of the earth so charged. This discharge heats the air and the dust particles through which it passes, the latter to brilliant incandescence as the electric current heats the filament in an incandescent light, so we see the flash of lightning. Furthermore, the great heat expands the air suddenly, and the thunderclap is produced just as a gun makes a loud noise when it goes off because the confined gases suddenly expand.

In 1789 what was supposed to be another sort of electricity was discovered. Galvani, an Italian, found quite by accident

that the muscles of the leg of a dead frog will twitch if the nerve in them is excited by frictional electricity. Having prepared several frogs' legs for further experiments, he hung each by a copper wire to an iron railing of the balcony outside his window. As they blew about in the wind, he noted with surprise that whenever one of the legs was thrown against the iron it was convulsed with a contraction. He thought the electricity that caused this must be generated by the animal and resided in its tissues.

When Alessandro Volta, a professor of natural philosophy at the University of Pavia in Italy, heard of this he repeated the experiment, but suspected that the electricity was coming from the copper and iron, bathed with moisture from the tissues. So he placed several cups in a small circle on the table, and filled them partly full of water. In each cup he stood a strip of zinc and, opposite it, one of copper so that the upstanding end of one copper strip leaned against the zinc strip in the next cup. The two strips in the same cup did not touch each other (Fig. 83). If, now, one copper strip was separated, by ever so little, from the zinc strip against which it leaned, a tiny spark appeared at the gap, showing that a current of electricity was being developed. He tried adding various substances to the water in the cups to see if the strength of the current might be increased. He found that any acid would do this very efficiently. Then he improved his apparatus. He piled up alternate plates of zinc and copper, separating them by flannel pads wet with acid, but connecting each plate with those on each side of it by short wires. One end of a wire, the other end of which was attached to the lowest zinc plate, was brought close to the free end of another similarly attached to the top copper plate. A much brighter spark showed a more powerful current. This device is still known as a voltaic pile, and we

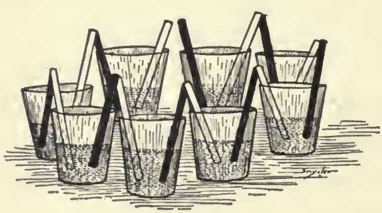


FIG. 83.—Volta's crown of cups

should now call Volta's "crown of cups" a group of batteries connected in series, as will be explained later. The electricity generated by such means came to be known as galvanic electricity from its discoverer, Galvani, who, however, misunderstood its source. Galvanic and frictional electricity are identical.

One day in 1819 when Hans Oersted, professor of physics in the University of Copenhagen, Denmark, was working with electric currents he noticed that a compass needle that happened to be standing on the table moved every time an electric current was sent through a wire near it. He began to investigate, and found (1820) that, when a wire is held over or under the magnetic needle and parallel to it, and an electric current is sent through the wire, the needle turns and tends to stand at right angles to the wire. If the current is strong it will assume such a position and keep it while the current is maintained.

André Ampère, who was a professor at the Polytechnic School in Paris, heard of this law that Oersted had discovered. He repeated the experiments, verified Oersted's results, but found out something more. He noticed that when the wire was held over the needle the north pole was deflected in one direction, but when held under the needle it turned in the opposite way. Furthermore, if the current in the wire held over the needle was going in one direction, the north pole of the needle was deflected one way, but if the current was reversed the north pole swung in the opposite direction. This law may now be stated thus: If you imagine yourself swimming, breast toward the needle, along the wire in the direction the current is going, the north pole of the needle will swing to your left. You may readily try this experiment for yourself with a compass and a copper wire, the ends of which connect with the binding-posts of an ordinary dry battery. The current is said to flow through the wire from the carbon at the center of the dry cell to the zinc at its edge.

Ampère applied this knowledge he had discovered to the construction of an instrument for detecting electric currents. A compass was wound with many turns of insulated copper wire

running parallel to the needle. The wire passed over the needle in one direction, under it in the opposite direction. When even a weak current is sent through the wire the needle is deflected. By noting in which direction it swings one can tell the direction of the current in the wire, and the amount of the swing tells something of the strength of the current. This instrument is called a galvanoscope (Fig. 84).

Ampère made another important discovery, namely, that, if currents of electricity are sent in the same direction, through two wires, set side by side and free to move, the wires repel each other and move apart. If the current is sent in opposite directions the wires attract each other and move together. You can verify this for yourself in this way. Fill a dish partly full of dilute sulphuric acid made by pouring the acid into the water. (The acid is likely to spatter if you pour water into it, and it burns badly.) Fasten with tacks a strip of zinc on one side of each of two good-sized corks so that it sticks below the cork an inch or two, and on the opposite side of each cork tack a similar strip of copper. Wind good-sized insulated copper wire (No. 16) about a pencil to make a right-handed coil as long as the diameter of the cork. Lay one of these coils on the top of each cork and fasten the ends of the wire, one to the tack that holds the zinc, the other to the tack that holds the copper. Now float the corks on the sulphuric acid in the dish. A current flows through each coil, for we have made a battery. The current flows in the wire from the copper to the zinc. Bring the corks close together with zinc strip facing zinc strip, and the corks come together, for the currents flow in the adjacent coils in

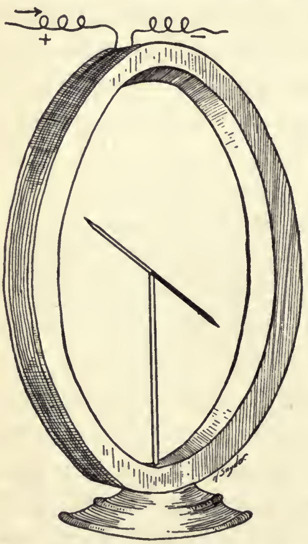


FIG. 84.—A simple galvanoscope

opposite directions. But let copper strip face zinc strip and the corks tend to float apart.

Ampère perceived from these experiments that there must be some intimate relation between magnetism and electricity, and he wondered if it might not be possible to make a bar of steel into a magnet by using electric currents. He tried various ways of doing this and finally hit upon this plan. He wound about a steel bar many turns of copper wire, covered with silk so that the electricity would not escape into the iron, and let a current of electricity run through the wire for some time. When he removed the windings from the steel bar, he found it was a magnet. This experiment is worth repeating. Wind a fairly coarse insulated copper wire about a bolt or nail, making many turns, and connect the ends of the wire with the binding-posts of a dry battery. You will find now without removing it from the windings that it is a magnet—an electromagnet, since it is made by electricity. Such a soft iron core does not remain a magnet when the current is turned off; it is a temporary magnet. It was later discovered, as we have shown above, that a coil of wire behaves as a magnet when a current is running through it. Its magnetic property is strengthened if the coil is wound about a core of soft iron.

An explanation somewhat as follows will serve to give a mental picture of what probably goes on in the iron bar when it is changed to a magnet. Conceive that the molecules of the iron are each a tiny magnet. They do not lie, in the unmagnetized bar, with their like poles pointing in the same direction but rather in any and all directions. They do not pull together, therefore, but at cross-purposes and so neutralize each other. When, however, the electric current flows in the wire wound about the iron bar, it causes the molecules to assume a position in which like poles all point toward the same end of the bar, when it becomes a magnet. In a soft iron bar the molecules resume their varying positions when the current ceases; but in a steel bar, which has greater rigidity since the molecules do not move readily, they remain

pointing in one direction after the current ceases and the bar is therefore a more or less permanent magnet.

Michael Faraday, of the Royal Institute in London, heard of Ampère's work, and thought that if a magnet can be made by passing a current of electricity through wire wound around an iron bar, the reverse of this also might be true, namely, that if a magnet were put into a coil of wire it would make an electric current flow in the wire. So he made a hollow coil of many turns of insulated wire, and connected the ends of the wire with a galvanoscope. Then he introduced one end of a strong bar magnet into the center of the coil, and saw that the magnetic needle did actually show a current. He found, however, that when the magnet was lying quietly in the coil no current was produced. It was only when the magnet was moving into or out of the coil that the current was manifest, and it flowed in one direction when the magnet was moving into the coil and in the opposite direction when it was moving out.

CHAPTER X

ELECTRICAL INVENTIONS

Invention breeds invention.—Emerson

Now all these discoveries, besides being interesting in themselves, led to a number of practical inventions of great importance. It has repeatedly been true that men have sought out nature's secrets to satisfy their curiosity without any thought of their immediate use, only to find in later years that the facts discovered were of immense value to man in increasing his happiness and well-being. So we support scientific investigations of all sorts in the belief that the facts discovered will some day be of use, even if at the present they cannot be turned to commercial account. They satisfy our longing to understand the universe about us, and this mental satisfaction is really quite as important as physical comfort and luxury.

The first of these great practical inventions in electricity was the telegraph. Two types of telegraph instruments were invented and put into general use. Wheatstone and Cook of England in 1837 patented an instrument that depended on the facts that a magnetic needle is deflected when an electric current is sent through a wire that passes over and under it, and that the direction of the deflection depends upon the direction of the current. The sending instrument consisted of a device for making and breaking the current and for reversing its direction at will. The receiving instrument was simply a magnetic needle mounted in a coil in such a way as to be free to swing in a plane at right angles to the plane of the coil. Then, by previously agreeing upon a set of signals to indicate the letters of the alphabet, it was perfectly possible to send a message. Thus, one swing of the north end of the needle to the left meant *c*, one to the left

followed by one to the right meant *a*, one left and two right meant *w*, etc.

Morse, in the United States, devised an instrument depending on the fact that, when an electric current is sent through a coil wound about a core of soft iron, the latter becomes a magnet but ceases to be one the minute the current stops. A sending instrument makes and breaks an electric current at the will of the operator (see diagram, Fig. 85). This instrument consists of a

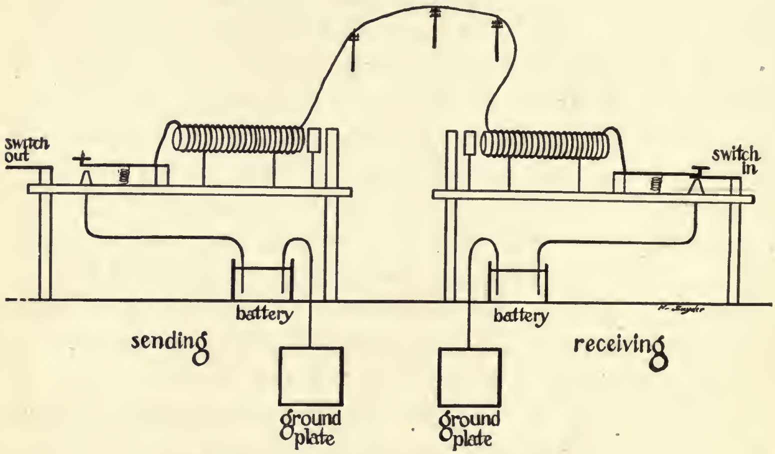


FIG. 85.—Diagram of an electric telegraph

metal bar hinged at one end to a post, and at the other end held directly over a second post by a spring. One wire from a battery attaches to this second post; the other battery wire runs to the ground. A wire attached to the bar runs through the receiving instrument of the second station. When the operator depresses the bar the circuit is made; when the pressure ceases, the bar springs back and the circuit is broken. The receiving instrument has a small iron bar held by a straight spring close to one end of the soft iron core within the coil (Fig. 86). When the current is made by the sending instrument, it passes to the coil of the receiving instrument and magnetizes the core. The bar is then forcibly drawn to the core, which it strikes hard enough to

produce a click. When the current is broken, the bar springs back and strikes a post with a click. If the current is made and broken immediately, the two clicks sound almost as one and represent a dot; if the current is allowed to run for a moment, the two clicks are distinctly separate and the signal stands for a dash. By various combinations of dots and dashes the letters of the alphabet are indicated. The Morse Code is given (p. 214) and the Continental Code is shown in parenthesis where it differs from the Morse Code.

There is a sending and a receiving instrument at each station. When one is receiving a message, he closes a switch in his sending instrument, so the current can pass through it to battery, ground, and back to the sending station (Figs. 85 and 86).

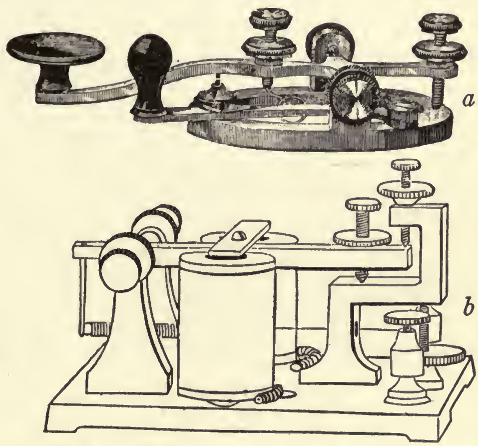


FIG. 86.—Telegraph instruments. (*a*) sending key; (*b*) receiving sounder.

When the early telegraph instruments were installed, two wires were run from station to station connecting the instruments. Later it was discovered that only one wire was necessary, for the earth would serve to complete the circuit. Now one wire is run from each instrument to a metal plate buried in moist earth; this is called the ground wire. At first, too, it was difficult to send messages a very long way, for it took a very powerful current to overcome the resistance in a long wire. Now, relay batteries that add to the strength of the passing current are introduced along the way. This, of course, is impossible in the long cables that carry the current under the sea from continent to continent, and in these a strong current must be used. In 1857 a wire was laid on the bottom of the sea between Dover,

England, and Cape Grisnez, France, and telegraphic communication was established for a few days until wave action broke the connection. The next year communication was re-established

THE MORSE[1] TELEGRAPHIC CODE

A	· —	
B	— · · ·	
C	· · ·	(— · — ·)
D	— · ·	
E	·	
F	· — ·	(· · — ·)
G	— — ·	
H	· · · ·	
I	· ·	
J	· — ·	(· — — —)
K	— · —	
L	——	(· — · ·)
M	— —	
N	— ·	
O	· · ·	(— — —)
P	· · · · ·	(· — — ·)
Q	· · — ·	(— — · —)
R	· · ·	(· — ·)
S	· · ·	
T	—	
U	· · —	
V	· · · —	
W	· — —	
X	· — · ·	(— · · —)
Y	· · · ·	(— · — —)
Z	· · · ·	(— — · ·)

1	· — — ·	(· — — — —)
2	· · — · ·	(· · — — —)
3	· · · — ·	(· · · — —)
4	· · · · —	
5	— — —	(· · · · ·)
6	· · · · · ·	(— · · · ·)
7	— — · ·	(— — · · ·)
8	— · · · ·	(— — — · ·)
9	— · · —	(— — — — ·)
0	——	(— — — — —)
.	· · — — · ·	(· · · · · ·)
,	· — · —	(· — · — · —)
:	— · — · ·	(— — — · · ·)
;	· · · · · ·	(— · — · — ·)
?	— · · — ·	(· · — — · ·)

Attention	· — · · ·
Separation	— · · · —
End of message	· · · — · —

through a well-protected cable. It was in 1858 also that the first attempt was made to lay a transatlantic cable, but communication was maintained for only a few hours. The first

[1] The International Code when different is given in parentheses.

successful transatlantic cable was laid in 1860 by the famous old steamer, the "Great Eastern" (Fig 87). Since then many other cables have been laid across the Atlantic and across the Pacific.

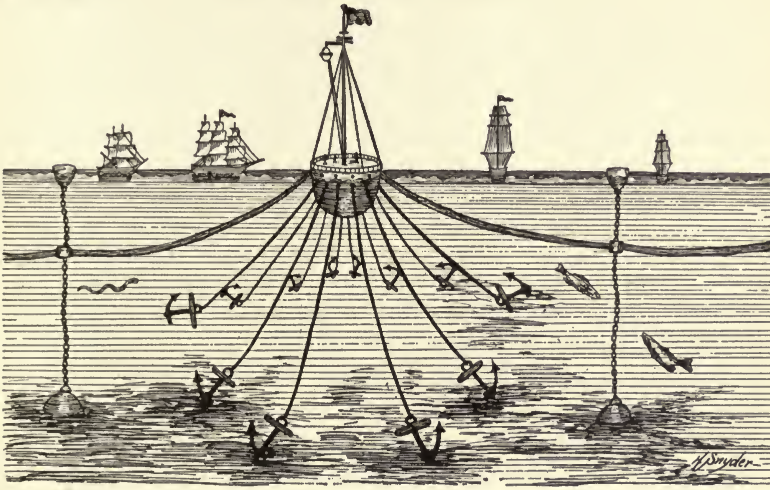


Fig. 87.—Laying the Atlantic cable, splicing the ends in mid-ocean. (Copied from the *Scientific American*, February 14, 1857.)

The following quotation from a contemporary account of the laying of the first Atlantic cable taken from the *Chicago Daily Press and Tribune* of Friday morning, August 6, 1858, shows the spirit of daring achievement that flavored these early attempts:

THE GREAT WORK OF THE AGE COMPLETED

Dispatch from Cyrus W. Field

Queen Victoria to Send the First Message

Trinity Bay, N.F., Aug. 5th

To the Associated Press:

The Atlantic Telegraph Fleet sailed from Queenstown on Saturday, July 17. Arrived at mid-ocean on Wednesday, the 28th; made the splice at 1 p.m. on Thursday, the 29th, then separated, the Agamemnon and Valorous bound to Valentia, Ireland, and the Niagara and Georgian for

this place, where they arrived yesterday, and this morning the end of cable will be landed.

It is 1,698 nautical or 1,950 statute miles from the telegraph house, at the head of Valentia Harbor, to the telegraph house at Bay of Bulls, Trinity Bay, and for more than two-thirds of this distance the water is more than two miles in depth.

The cable has been laid out from the Agamemnon at about the same speed as from the Niagara. The electrical signals sent and received through the whole cable are perfect. The machinery for paying out the cable worked in the most satisfactory manner, and was not stopped a single moment from the time the splice was made until we arrived.

Captain Hudson, Messrs. Everett and Woodhouse, the engineers and electricians, and officers of the ships, and in fact every man on board the Telegraph Fleet, have exerted themselves to the utmost to make the expedition successful and by the Divine Providence it has succeeded. After the end of the cable is landed and connected with the land line of the telegraph, and the Niagara has discharged some cargo belonging to the Telegraph Company, she will go to St. Johns for coal, and proceed at once to New York.

CYRUS W. FIELD

LETTER FROM MR. FIELD TO THE PRESIDENT,

PHILADELPHIA, August 5th.—The President, who is at Bedford, received the first intimation of the successful laying of the Atlantic Cable through the Associated Press. The following is a copy of Mr. Field's message to the President of the United States, at Washington:

DEAR SIR: The Atlantic Telegraph cable on board the U.S. steam frigate Niagara and her British Majesty's Agamemnon was joined in mid-ocean, July 29th, and has been successfully laid; and as soon as the two ends are connected with the land lines, Queen Victoria will send a message to you, and the cable will be kept free until your reply has been transmitted. With great respect,

I remain

Your obd't serv't,

CYRUS W. FIELD

Not only is it now possible to send messages by telegraph, which are then printed at the receiving station by the electric receiving apparatus, but signatures and photographs can also be faithfully transmitted. The principle of the transmission of a photograph is perfectly simple even if it is marvelously ingenious.

The photographic print is moved back and forth between two terminal points of an electric circuit, one touching the upper surface of the picture, the other the under surface. These points move along a series of parallel lines, from one end of the print to the other. The current that flows in the circuit varies according to the amount of silver deposit at every point of the print. Where the silver deposit is heavy so that the print is dark, the metal acts as a good conductor and the current flows readily, but where the print is light, the flow of the current is weak. At the receiving station a piece of sensitized paper is made to move mechanically in correspondence with the movement of the print. A beam of light strikes at a point on this paper, and as the paper moves this point of light runs over its surface in parallel lines corresponding to those over which the terminal points are moving upon the print. This beam of light is focused on the paper through a piece of selenium, through which also flows the current coming from the transmitting station. Selenium has this peculiar property, that the stronger the electric current flowing in it, the more readily it permits light to pass through it. When, therefore, the terminal points are traveling over a dark part of the print, the current transmitted is strong, the selenium permits much light to pass through it, the sensitized paper is strongly acted upon, and prints dark. Thus the sensitized paper reproduces point by point the dark and light areas of the original print.

When the telegraph was invented, it seemed wonderful enough that men could send intelligible messages over a wire for hundreds of miles, but it seemed past belief when it was announced that one could talk into a small instrument and be heard distinctly miles away by another person who held to his ear a receiver connected only by a wire with the sending instrument.

As in the case of most inventions the possibility of the telephone occurred to several persons, and rude attempts were made to produce it years before the practical instrument was devised. Credit is due to Page, an American (1837), to Froment (1850), to Bour-Seul (1854), and to Philippe Reiss, a science teacher in a

little German town, who in 1860 applied the name "telephone" to his invention. But Alexander Graham Bell is looked upon as the real inventor of the telephone, although a few hours after he had filed his papers at the Patent Office in Washington (1876), Elisha Gray, of Chicago, filed his papers covering the invention of an instrument for a similar purpose. Bell's was the more practical as well as the prior invention, and the present instrument is still called the Bell telephone, although his original device has been greatly modified.

Bell, the son of an Edinburgh clergyman, received a literary education. As a young man he emigrated to the United States and became instructor in an institution for deaf-mutes in Boston. This experience centered his attention on sound and hearing. He realized that, in hearing, the ear drum is made to vibrate by waves of sound, and that, in speaking, such waves are caused by the vibrations of the vocal chords. He conceived the idea that such sound waves might be produced by a vibrating membrane operated by an electric current in harmony with another membrane at some distance, whose vibrations were produced by the voice of a person speaking against it. He used to remark that it was well he had received a literary rather than a scientific education, for if he had known anything about electricity he would never have had the audacity to think such a thing possible. He was, however, encouraged by Joseph Henry, of Philadelphia, then the American master of electrical science.

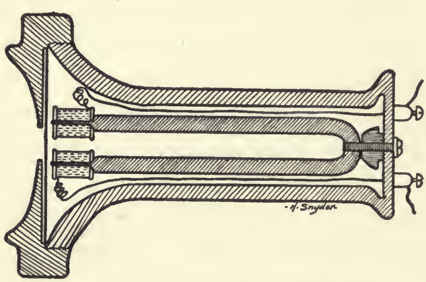


Fig. 88.—Diagram of a telephone receiver

In the early instruments the transmitter and the receiver were much alike. Each consisted of a thin steel diaphragm mounted near one end of a soft iron core, wound with insulated wire (Fig. 88). One of the two wires of the operating battery

ran to the ground, the other was joined to the wire wound about the transmitter core. From this coil the current ran through a wire connecting with the other station, where, after passing through the coil about the receiver core, it was carried to the ground which served to complete the circuit. When one spoke into the transmitter, his voice caused a vibration of the diaphragm. As the diaphragm bent toward or away from the soft core, magnetized by the flowing current, it caused a fluctuation in the intensity of the current, because it was itself an induced magnet moving in relation to a wire coil. These changes in the intensity of the current carried from the transmitter caused the core of the receiver to vary the magnetic pull on its diaphragm in accordance with the vibrations of the diaphragm of the transmitter, and the receiving diaphragm vibrated so as to reproduce the speaking voice.

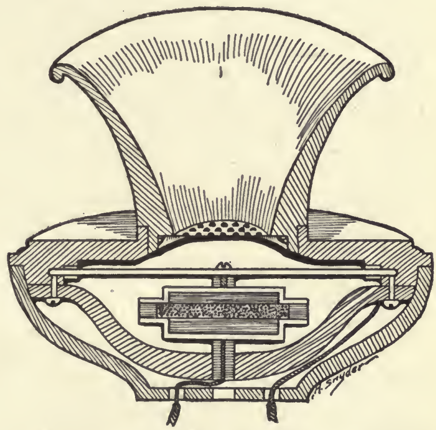


FIG. 89.—Diagram of a microphone transmitter

In 1856 Du Moncel discovered that, when a rod of carbon forms part of an electric circuit, compression of the carbon facilitates the flow of the circuit. In 1877 Edison applied this principle for making an improved telephone transmitter (Fig. 89). The diaphragm of this transmitter rests lightly against carbon granules held in a shallow cup of hard rubber. As the current introduced through metal strips flows through these carbon particles, its intensity is increased or decreased according to the pressure of the diaphragm. This makes a much more sensitive transmitter than the earlier type.

In its early history, when two people wished to talk to each other over the telephone, their two instruments were connected

directly by a wire. As telephones multiplied, it was evidently impossible to have wires running from each instrument to every other with which the owner of one might wish to communicate. A central station was therefore established to which the wires of all instruments were run and where they might then be connected as desired. Each wire running from a subscriber's telephone to

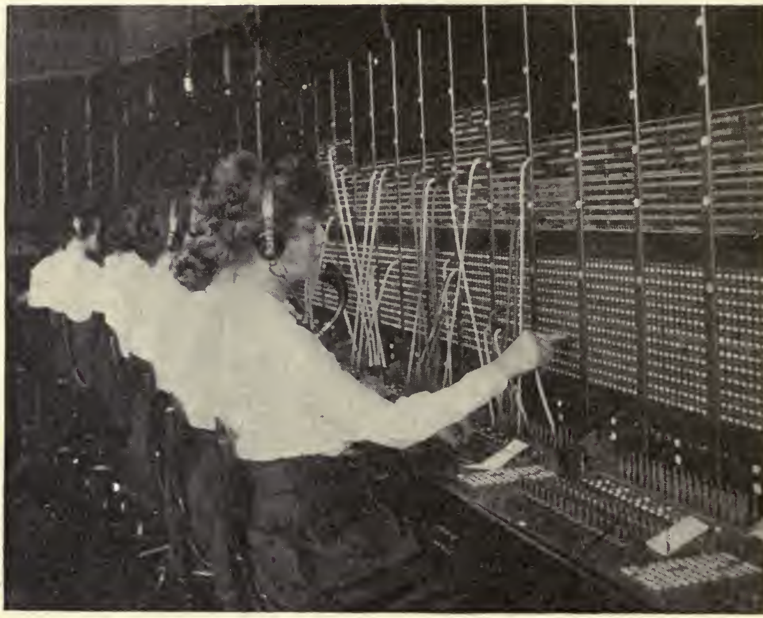


FIG. 90.—A modern telephone exchange switchboard. (Courtesy of the Illinois Bell Telephone Co.)

"central" is bifurcated, one branch ending in a plug socket on a switchboard, the other in the plug. Directly over the socket, and wired to it, is a tiny electric lamp, which lights when the subscriber rings up "central," and remains lighted until she connects her receiver with this socket and learns what subscriber is wanted. She then disconnects her receiver and connects the plug of the desired subscriber's wire with the socket of the calling subscriber.

In a great city, where there are hundreds of thousands of subscribers (there are over 6,000,000 in Chicago), there must be a number of centrals, for since most calls are between neighbors a nearby exchange can care for these without the expenditure necessary to carry all the wires to a single office. When you call a person in a distant part of the city, the local central connects your wire with that of the distant exchange, and the operator there plugs the wire from your local central into that of the subscriber with whom you wish to talk. Therefore, it is necessary when calling to give not only the desired number but also the name of its local exchange (Fig. 90).

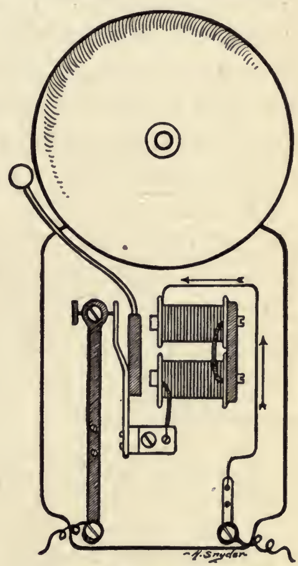


FIG. 91.—Diagram of an electric bell.

Recently the automatic switchboard is being introduced to replace the operators at central, for an electric device is cheaper and more dependable than a person, and the task of an operator is very fatiguing. These new automatic centrals will free human beings for more worth-while tasks. It seems very remarkable that a mechanical contrivance can so efficiently replace the intelligent action of the central operator.

The electric bell has a hammer attached to an iron bar so mounted that it will be forcibly drawn to the magnetized soft iron core of a coil when an electric current is sent through the latter. As the bar moves, the hammer strikes the bell. It will be seen that the principle of operation is very much like that of the sounder or receiver of the Morse telegraph (Fig. 91). In the bell, however, an ingenious device causes the hammer to strike the bell repeatedly. The current goes to the coil through two points which are in contact when the hammer is at rest, but

which are separated when the hammer is pulled over so as to strike the bell. When the current ceases to flow in the coil, its core ceases to be a magnet, and the iron bar with its attached hammer is drawn back by a spring to its initial position. Thus contact between the points is again established, the core of the coil again becomes a magnet, and the hammer again strikes the bell. This process is repeated much more rapidly than it can be described. The bell therefore rings with a rolling note like that of a drum. The electric buzzer is similarly constructed and operated, but since it has neither bell nor hammer, only a rattling noise is produced as the iron bar strikes first the core of the coil and then the post that bears the contact point (Fig. 92).

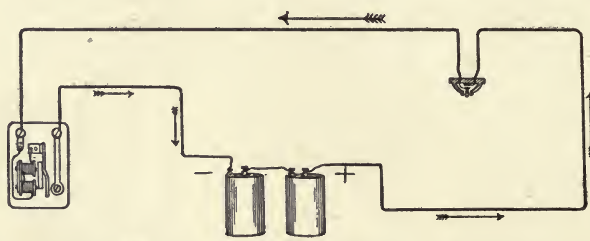


FIG. 92.—Diagram of a buzzer, push button, and batteries connected up properly.

The rapid increase in the use of telegraphic communication created a great demand for more efficient types of batteries. Since Volta first discovered how to make a battery to produce the so-called galvanic electricity, very many types of batteries have been produced, though the principle of operation is much the same in all. The succession of events that produces the electric current may be described for one or two types of cells.

When a strip of copper and a piece of carbon, such as an old electric light carbon, are partially immersed in dilute acid at the opposite sides of a tumbler, and their free ends are connected by a wire, a simple battery is made, and an electric current flows through the wire. The copper replaces the hydrogen of the acid, forming copper chloride, $CuCl_2$. This in part ionizes, separating

into copper and chlorine ions. The copper, which a moment before was in a neutral molecular state, now in its ionic condition, bears an excess of two positive charges on each ion. To accomplish this change two electrons or negative charges have been left on the copper plate. Since countless numbers of copper molecules are rapidly making this change, the copper plate is negatively charged. At the opposite side of the battery, metallic copper is depositing on the carbon. The positively charged copper ions change to a neutral molecular state by drawing negative electrons from the carbon, so that the latter is left with a positive charge. There is thus produced a difference in electric pressure, and a current flows in the wire in consequence. In all the literature of batteries it has been the custom to speak of the current as flowing in the wire from the positively charged carbon to the negatively charged copper. Now physicists believe that it is the movement of the electrons from the copper plate to the carbon that makes the current in the wire. In spite of this, however, we follow the old custom and speak of the current as flowing from the positive to the negative pole. Before the free ends of the copper and the carbon are connected in such a simple battery, it will be noticed that chemical action is going on rapidly at the copper strip, while little or no action occurs at the carbon. Hydrogen bubbles are rapidly evolving as the copper takes the place of the hydrogen in the acid. When, however, the elements of the battery are connected by the wire, the hydrogen nearly ceases to appear at the copper pole, but accumulates rapidly on the carbon. The copper of the plate drives off the hydrogen in the molecules of acid next to it. This nascent hydrogen is very active, and replaces the hydrogen of the next adjacent molecules. So the hydrogen is passed from molecule to molecule across the battery somewhat as a football might be passed down a line of players. Thus it arrives at the carbon pole without being visible in transit.

Such a battery will not operate very long, however, for the bubbles of gas accumulate on the positive plate, and prevent the

passage of the current. This difficulty is overcome in several ways: First by using chemicals which will not liberate hydrogen as in the gravity battery described below, or secondly by the use of some chemical which unites with the hydrogen. Thus in the chromate battery a solution of potassium bichromate, $K_2Cr_2O_7$, is used. This readily gives up a part of its oxygen, and the oxygen and hydrogen unite to form water.

In general, when two substances like plates of two metals are partially immersed in a chemical and chemical action occurs,

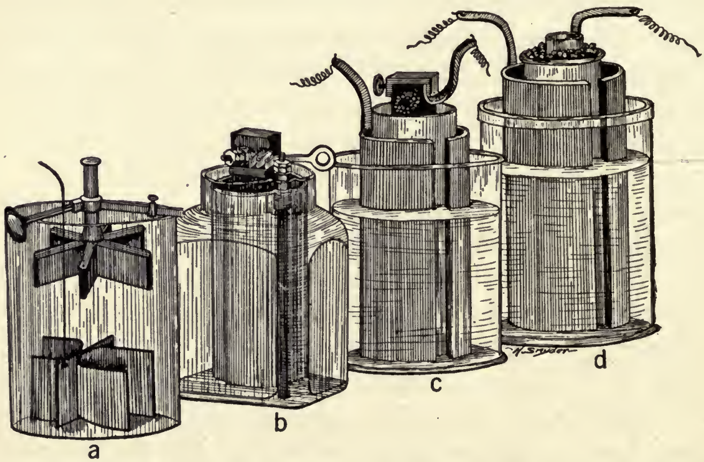


FIG. 93.—Several types of batteries: (*a*) gravity battery; (*b*) bichromate battery (La Clanche); (*c*) Bunsen battery; (*d*) Daniell battery.

the electric current passes in a wire connecting the plates from the one where chemical action is less rapid to the one where it is more rapid. Thus if a zinc and a copper strip were used in the simple battery described above, the copper would be the positive plate and the zinc the negative.

The development of the electric current is explained in the gravity battery somewhat as follows (Fig. 93). This battery consists of a jar with a copper plate at its bottom and a zinc plate near its top. A solution of common salt is used to fill the jar, into which some copper sulphate crystals are thrown. Some of

this copper sulphate goes into solution, but since its specific gravity is high the solution remains at the bottom of the jar, the salt solution above it. The zinc replaces the copper in the copper sulphate solution, and the zinc sulphate ionizes. The zinc thus changes from the neutral molecular condition to the ionic condition with an excess of two positive charges to each ion, by discharging two electrons from each atom on to the zinc plate, which as this process continues becomes negatively charged. The copper moves to the copper plate, and is deposited as metallic copper. As it makes this change from the ionic to the molecular state, it must take on electrons, drawing them from the zinc plate through the connecting wire. Since the copper plate is constantly giving up electrons, it has an excess of positive charges and is positive. The flow of electrons is, therefore, from the zinc to the copper plate. In this battery the zinc gradually disappears, the copper sulphate is also used up, and crystals of zinc sulphate are deposited.

There is an instructive analogy between the flow of water through pipes connected with a reservoir and the flow of electricity through the wires connected with a battery. In the former the amount of water discharged depends, first, upon the head of water in the tank or upon the pressure at the opening (the greater the pressure, the more rapid the flow), and, second, upon the character of the pipe; a long pipe diminishes the flow by the friction of the water on its sides more than does a short pipe of the same diameter; a pipe with rough interior reduces the flow more than one with a smooth lining, and a small pipe carries less water than a large one of the same material. (See p. 113.) Similarly, the flow of electricity from a battery depends, first, on the electric pressure developed by the battery (the greater the pressure, the greater the flow) and, second, upon certain properties of the wire; a long wire offers more resistance than a short one of the same substance and diameter; a fine wire offers more resistance than a coarse one; copper, which is a good conductor, offers less resistance than iron, and both are better conductors

than glass, which scarcely permits any electricity to flow through it, and so is called a non-conductor. Recall the heat conductivity of these substances, page 153. Furthermore, if a pipe carrying water branches, the flow in each branch will be in proportion to its capacity; if one branch has a cross-sectional area twice that of the other, it will carry twice as much water. Similarly, if a wire carrying a current branches, the flow of current in each branch will be proportional to its capacity; if the circuit supplied by one branch offers much resistance, while the other offers little, the latter will carry the major part of the current.

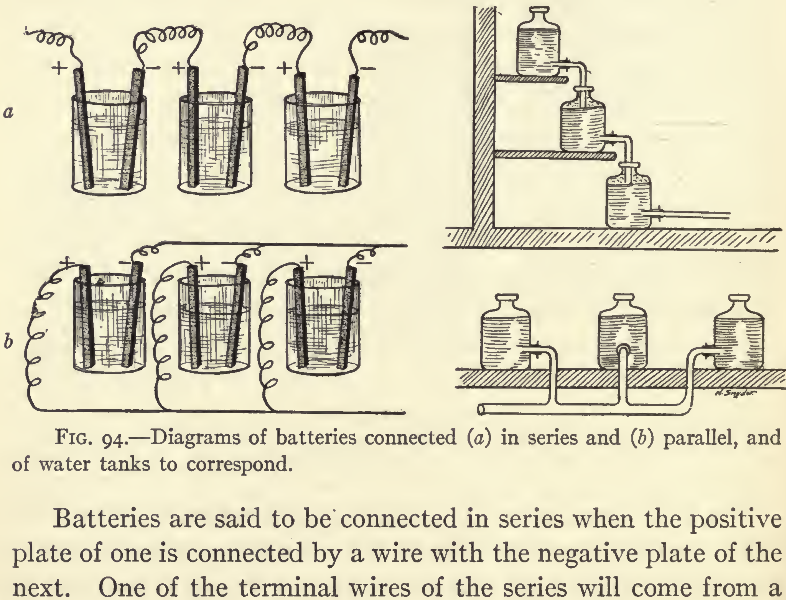


FIG. 94.—Diagrams of batteries connected (*a*) in series and (*b*) parallel, and of water tanks to correspond.

Batteries are said to be connected in series when the positive plate of one is connected by a wire with the negative plate of the next. One of the terminal wires of the series will come from a positive plate, the other from a negative. Batteries are said to be connected parallel when the positive plates of all are connected by one wire, and the negative plates of all are connected by another wire. When two or more batteries are connected in series, the effect is similar to that of mounting one water-tight reservoir above another and connecting them by pipes. The pressure of water in the upper tank is added to that of the lower,

and the water outflows from the latter with a force equal to the sum of the pressures. If batteries are connected parallel, the effect is similar to connecting a small pipe running from each of several water tanks standing at the same level with one large pipe (Fig. 94). The combined outflow is greater, but the pressure in the large pipe is no greater than it is in a small pipe running from one tank. Stated in electrical terms, we say that when batteries are connected in series the current has a voltage equal to the combined voltages of the several batteries, but the amperage is no greater than that of one of the batteries. When connected in parallel, the amperage is increased while the voltage remains the same.

Resistance is measured in ohms. The ohm is about the resistance offered by 9.3 feet of No. 30, American gauge copper wire. To overcome high resistance, high electric pressure must be used. Electric pressure is expressed in terms of volts. Just as with liquids, so with electric currents, the greater the pressure, the greater the flow, other things being equal. The unit that is used in measuring the rate of flow of electricity is the ampere. It is defined as that amount of current which, while flowing through a standard solution of silver nitrate, such as is used in silver plating, will deposit a specified amount of silver (0.001118 grams) per second. The electric pressure that will force a current of one ampere through a resistance of one ohm is designated the volt.

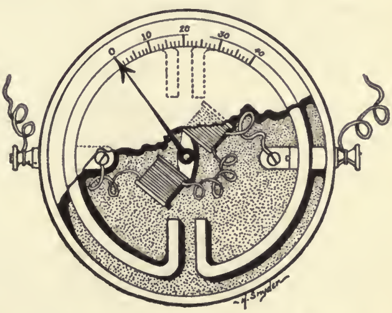


FIG. 95.—Diagram of an ammeter

The instrument used for measuring the amount of current flowing in a wire at any minute is called the ammeter (Fig. 95). A soft iron core wound with insulated wire is pivoted at its midpoint, and so mounted between the ends of a permanent magnet

that, when the current to be measured is sent through the wire, the core turns on its pivot, repelled by the magnetic poles. When the current ceases to flow, the iron core is returned to its original position by the action of a spring. A hand like that of a watch is attached to the core over the pivot, so that its free end moves over a graduated scale on the face of the ammeter. The greater the amperage, the greater the deflection of this hand.

The voltage of the current is measured by a similar instrument, the voltmeter. In this meter, a part of the main current is shunted off through a fine wire wound about the core. The greater the voltage, the greater the current that flows in this wire and the more the needle is deflected.

Both instruments may be combined in one, the voltammeter. In this instrument the needle is deflected in one direction for measuring the amperage and in the opposite direction for measuring the voltage.

It will be seen later that electrical energy may easily be transformed into mechanical energy by means of the motor, and that mechanical energy may be transformed into electrical energy by means of the dynamo. Electrical energy is turned into heat by such devices as the electric flatiron, the hot-point heater, etc. It is convenient, therefore, to have exact equivalents of electrical energy in terms of mechanical energy and of heat.

It is found that a current of one ampere working under pressure of one volt will do work equivalent to 1/746 of one horse-power. This unit is known as the watt. It is evident then that volts multiplied by amperes divided by 746 equals horse-power. Electric current is usually sold at so much per kilowatt-hour, the unit being a thousand watts of electrical energy furnished every hour. The instrument for measuring this consists of a small motor that runs on the current and turns cogs that operate the hands on the dials by which the meter is read (Fig. 96).

The kilowatt-hour equals 3,600,000 joules of heat energy. Or one may express the heat equivalent of electrical energy in calories by stating that the number of small calories equals .24

of the resistance expressed in ohms, multiplied by the square of the current intensity expressed in amperes, multiplied by the time expressed in seconds.

$$c = .24 \times R \times I^2 \times t.$$

Each of the many kinds of available batteries possesses certain advantages but also certain disadvantages. There is,

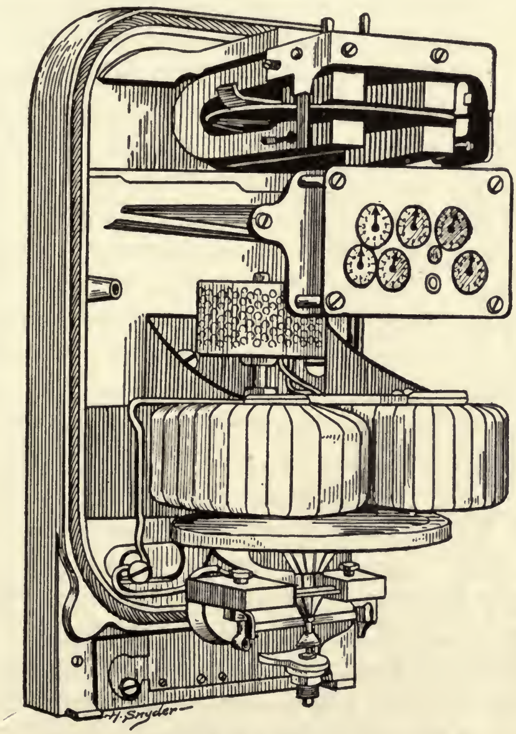


FIG. 96.—Diagram of a kilowatt-hour meter

therefore, no single battery which is superior for general use. A battery must be selected for the particular work it is intended to accomplish. The several kinds of batteries differ from each other chiefly in their length of life and in the voltage of the current produced, its electromotive force, its constancy, its

cost of production. Furthermore, some batteries discharge undesirable fumes.

The gravity battery already described is long-lived, and gives a very steady current. It is much used for telegraph and telephone lines, though in large plants dynamos are now replacing batteries.

In a common style of bichromate battery, a zinc rod is immersed in dilute sulphuric acid held in a tall, porous earthenware cup at the center of the battery jar. Outside this cup is the solution of potassium bichromate and at the periphery of the jar is a cylindrical sheet of copper. The porous cup prevents the mingling of the bichromate solution with the acid, but permits the passage of the current and of the hydrogen, which, when oxidized by the bichromate, forms water. This battery gives a current of considerable voltage (2 volts), and permits intermittent use without much deterioration. It is serviceable for running electric lights that are only occasionally used (Fig. 93, p. 224).

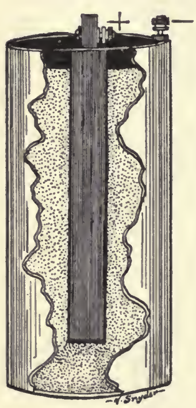


FIG. 97.—Diagram of a dry battery.

The Bunsen cell has a carbon rod immersed in nitric acid in a porous cup at the center of a battery jar, while a zinc plate is immersed in sulphuric acid outside the porous cup. This battery is inexpensive to run, and gives a current of good voltage and great constancy, but unfortunately gives off disagreeable fumes of nitrous oxide. Still, it is a serviceable battery for furnishing the current for electrical experimentation.

Since it is not always convenient to use a battery containing liquid, the so-called dry battery has been devised (Fig. 97). This is familiar in the pocket flash light and in the bicycle headlight, and is now used for ringing door bells and for similar domestic purposes. Such a battery is really not a perfectly dry cell, but the moisture which is essential to any battery is

held in an absorbent substance as water is held by a sponge. A cylindrical copper or sheet zinc cup is nearly filled with a moist mixture of ammonium chloride, manganese dioxide, and charcoal, each powdered. A rod of carbon is placed in the center of the cup, whose open end is then sealed with asphalt or a similar substance, through which the rod protrudes. One of the binding-posts foı the wires is attached to this projecting rod, the other to the copper or sheet zinc cup. The ammonium chloride reacts with the copper giving ammonia and copper chloride, which later ionizes. The ammonia is oxidized by the manganese dioxide which becomes the simple oxide. The charcoal serves to hold the moisture and to absorb excess of gases formed.

The so-called storage battery commonly used in automobiles to furnish current for the starter and for the spark plugs is not a battery in the same sense as those described. It does not produce electric energy, but merely stores it.

Early in the nineteenth century it was accidentally discovered that when a current of electricity is sent from a strong battery into a weak one, the latter becomes charged and will, when used, give off a relatively strong current. It was not, however, until in 1859, when Plante discovered the peculiar adaptability of lead for use in the storage battery or accumulator, that such batteries became really serviceable. The principle of operation is simple. When a current is sent into a storage battery, its energy is there used to accomplish certain chemical changes. Then, when this charged battery is used, these chemical changes reverse, and the battery gives off the electric current that was used in their production. This current comes off in a reverse direction from that of the charging current.

The most commonly used storage battery (Fig. 98) consists of two sets of lead plates, those of one set closely alternating with those of the other, and all immersed in dilute sulphuric acid (15–30 per cent in distilled water). When the battery is being charged, one set of plates is connected with the positive pole (anode), and the other with the negative pole (cathode), of a

battery or other source of electricity. As a result of the charge, the plates connected with the cathode are coated with lead peroxide (Pb_2O_5). Now, when the battery is being used, the lead plates that were connected with the anode become the cathode, and those that were connected to the cathode become the anode. The lead peroxide (Pb_2O_5) readily breaks down, yielding oxygen which unites with the hydrogen of the sulphuric acid, thus liberating SO_4, which goes to the anode and unites with the lead, forming lead sulphate, $PbSO_4$. As the lead peroxide, Pb_2O_5, changes to the oxide, PbO_2 ($Pb_2O_5 = 2\ PbO_2 + O$), the lead is becoming less positive by taking on electrons drawn from the anode plate, thus leaving it positive. At the other plate where the lead sulphate is forming and ionizing, neutral molecular lead is changing to positive lead ions by giving up electrons to the cathode, which is therefore negative. When the battery is charged, the reverse process takes place. The electricity flowing into the battery decomposes the water, the hydrogen going to one pole, the oxygen to the other. The oxygen now changes the PbO_2 to Pb_2O_5, while the hydrogen displaces the lead in the lead sulphate, thus forming sulphuric acid. The lead so displaced deposits on the plate. During the discharge of the current, the movements of the electrons are just the reverse of those described above.

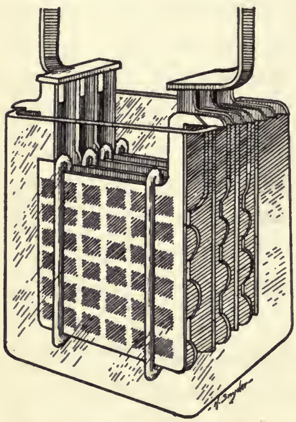


FIG. 98.—Diagram of a storage battery.

WHEN CHARGING

Anode or	$PbSo_4$		H_2O			Cathode
positive	decomposes		decomposes			or
plate	$\leftarrow Pb$	$So_4 \leftarrow$	H_2	$O \rightarrow$	unites with PbO_2	negative
			unite to		to form $Pb_2O_5 \rightarrow$	plate
			form H_2So_4			

WHEN DISCHARGING

H_2So_4 Pb_2O_5 $\leftarrow$ Anode

decomposes decomposes

Cathode unites with $\downarrow$ $\downarrow$ yielding

$\rightarrow$ Pb $\leftarrow SO_4$ H_2 $\leftarrow$ O

forming $PbSo_4$ unite to form

H_2O

The lead plates in stationary storage batteries are usually honeycombed in order that they may carry a larger amount of peroxide and may also present a greater surface for chemical action. But in storage batteries that are subject to constant jar, like those of automobiles, plain plates must be used since the jarring detaches flakes of the peroxide which are likely to lodge between the anode and cathode and so short-circuit the battery. Batteries in automobiles must, therefore, be frequently recharged, while stationary batteries can take a charge that will last a long time.

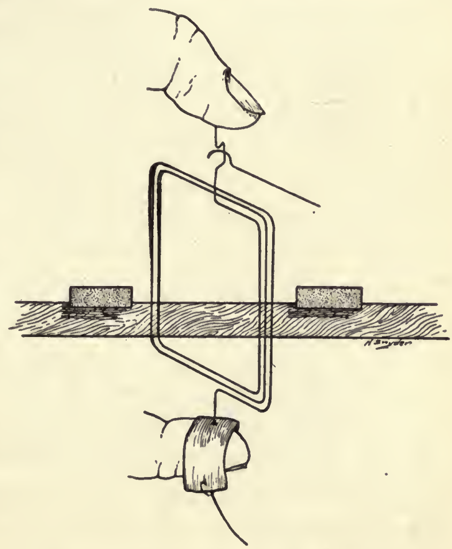


FIG. 99.—Diagram of an electric motor reduced to simple terms.

When Ampere discovered that a current flowing in a wire makes the wire behave as a magnet, the foundation was laid for the electric motor. An electric motor reduced to very simple terms may be thus made (Fig. 99). Lay two bar magnets on the edge of a table with the north pole of one and the south pole of the other projecting over the edge an inch or so, and the two poles about 2 inches apart. Take a piece of 16-gauge insulated

copper wire some 20 inches long and bend it so as to make a rectangle 2 inches long and $1\frac{1}{2}$ inches wide of several parallel turns of the wire. Bend out one end of the wire at the middle of one end of the rectangle so that it extends out about $\frac{1}{2}$ inch in the plane of the rectangle and at right angles to its end. Similarly bend out about $1\frac{1}{2}$ inches of wire at the other end of the rectangle and strip off its insulation. We will call this last end of the rectangle its top. Now bend this wire at the top of the rectangle so as to make in it a square open on one side, the plane of the square to lie at right angles to the plane of the rectangle. File off the ends of the wire until they are smooth and rounded. Cut a small piece of sheet copper about $1 \times \frac{1}{2}$ inch. At one end of this make a dent, and near the other end punch a hole with a nail point. Fasten one end of a 2-foot length of copper wire to this copper strip through the hole and the other end to a free pole of three dry batteries connected in series. Connect one end of another 2-foot length of wire to the other free pole of the batteries and bend the other end, which has been bared, to make a small semi-circle. Lay the bit of copper sheet on the end of the middle finger of your left hand, set the tip of the wire that projects from the bottom of the rectangle in the dent in this, and hold the other end of the wire of the rectangle against the ball of your thumb. Hold the rectangle thus, vertically, between the ends of the bar magnets. Now hold the second wire in your right hand and bring its free curved end into contact with the wire of the open square. The wire rectangle should now rotate rapidly on its axis. You may have to start the rotation with a light push of the finger. Suppose the bit of sheet copper is connected with the carbon (positive) pole of the battery. The current enters the wire through it, and in our diagram passes up the wire at the right side of the rectangle. If the adjacent pole of the magnet is the north pole, the wires tend to attract it, or since the wires are free to move and the heavy magnet does not move readily, the wire will be attracted by the magnet and so turns to the right. (A more exact explanation is given later,

see p. 238.) On the other side of the rectangle the current is moving down instead of up, and consequently will be attracted by the south pole. The curved wire loses contact with the wire of the open square as the rectangle turns, but the momentum of the rectangle carries it on around until contact is again made and the process just described is repeated.

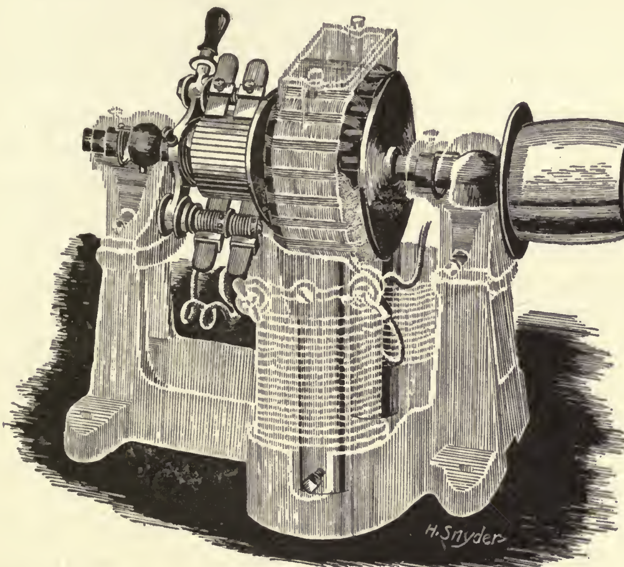


FIG. 100.—Diagram of a commercial electric motor, skeleton view. (After Trevert.)

The commercial motor (Fig. 100) is made up of a number of such simple rectangular units, each consisting of many turns of wire instead of a few. These units may be so mounted that they have a common axis, which is also the axis of an iron cylinder. The tops and the bottoms of the rectangles are, therefore, diameters of the ends of the cylinder. The sides of the rectangles lie in the surface of the cylinder, separated from each other by a few degrees of space. This structure is mounted on an axle coincident with the axis of the cylinder. The ends of the wire of each unit are both brought to the same end of the rectangle

and attached to narrow copper strips that lie on opposite sides of the axle in the plane of the unit. This pair of copper strips is completely insulated from the next adjacent pair. This series of metal plates borne on the axle is known as the commutator. The current enters and leaves the units by two copper strips that are applied on opposite sides of the commutator.

Instead of using permanent magnets the commercial motor uses electromagnets. A part of the current entering the motor is shunted off through a branch wire, which is wound about a horseshoe-shaped core, transforming it into a magnet. The cylinder of rectangular units, known as the armature, revolves on its axis between the poles of this magnet. The explanation of the rotation is the same as that given for the simple unit; but no sooner has one unit revolved so that its strips on the commutator have lost contact with the strips that supply the current than another unit receives the current. This unit is forced to rotate in the same direction, and so the armature continues to revolve.

There are many types of commercial motors, which differ from each other principally either in the method of winding the wire on the armature, in the arrangement of the coils, or in the arrangements of the magnets. Each of these various types possesses certain advantages, and each is adapted to a particular sort of work. Some of them will run only on an alternating current, others on a direct current. This point will be better understood after the discussion of magnetos and dynamos.

One other simple type of motor may be described that is often used in schools as a demonstration motor, and that is sold in shops as a toy. Imagine a rimless wheel, with three equidistant iron spokes, to be so mounted that it will whirl between the ends of a horseshoe-shaped electromagnet (Fig. 101). The current flowing into the motor is divided. Part of it goes through a wire that is wound first about one arm of the horseshoe-shaped iron in an anticlockwise direction, and then in a reverse manner on the other arm of the iron. Thus the current makes one pole the north pole and the other the south pole of the electromagnet.

The remainder of the current goes to a binding-post at *d*, thence through metal strips that are held in contact with the commutator by their springiness, and out at *e*. The commutator here consists of three pairs of copper strips each insulated from its neighbors. The members of each pair are fastened to the opposite sides of the axle of the armature. (See II and III of Fig. 101). The members of each pair are also attached to the ends of a wire wound about one of the radial iron spokes or cores. Thus *f* and *g* are attached to the ends of a wire that is wound in a

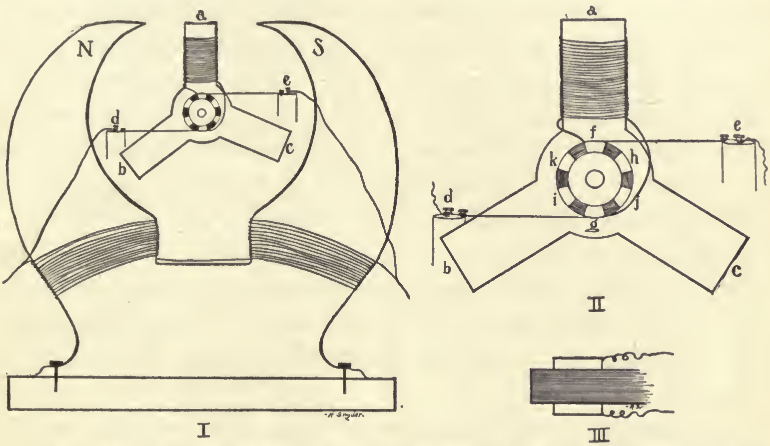


FIG. 101.—Diagram of a toy motor. I, sectional view of the motor; II, the armature enlarged; III, diagrammatic side view of commutator.

clockwise direction about the upper one of these radial soft-iron cores. When the current is flowing through this wire, the free end *a* of the core is a south pole. It is, therefore, attracted to the nearby north pole of the electromagnet and so causes the armature to whirl in an anticlockwise direction. In a sixth of a revolution of the armature, *h* and *i* are in contact with the metal strips bringing in the current. They connect with the wire that is similarly wound about the core whose free end is at *b*. But the current goes through this wire in a reverse direction from that which it had in the first coil; the free end *b* is, therefore, a north pole, and is repelled by the adjacent north pole of the

magnet. This turns the armature so that the free end *c* comes into the position first occupied by *a;* it is made a south pole, and thus the whole process is repeated.

How the wires on the horseshoe magnet and the radiating cores must be wound to produce the results described will be clear if a simple law already learned is recalled (p. 207). If an electric current is sent through a circular loop of wire placed about a magnetic needle or small bar magnet that is free to swing on its mid-point in a horizontal plane at right angles to that of the loop, the needle or magnet is deflected. If a strong current is used or if many turns of wire in a flat coil be used in place of the single loop, the deflection is very marked, and the needle will assume a position such that its long axis is perpendicular to the plane of the coil. Furthermore, the direction of deflection will be constant. If you imagine yourself swimming along the wire in the direction in which the current is flowing, your chest toward the needle, the north pole of the needle is always turned to the left. Evidently the loop of wire is the equator of a magnetic field whose south pole attracts the north pole of the needle and coincides with it when the needle attains its maximum deflection.

If a current is sent through a spirally coiled wire whose turns run in the same direction as the hands of a clock, or as the turns of the thread on a right-handed screw, the spiral coil behaves as a magnet, and magnetizes a soft-iron core placed within it. Applying the same swimming figure for determining its polarity, evidently the end of the coil toward which the current is moving is the south pole, while, if the turns of the wire are left-handed or anticlockwise, the pole is a north pole.

The electric motor is an exceedingly convenient device for the application of power. It may be mounted directly on the shaft that is to be turned, instead of being connected with it by a crank shaft or by belting and pulleys, as is usually necessary when a steam engine is used as the source of power. As it occupies little space in proportion to the power developed, it

can be mounted on the tool itself as on the drill, the planer, the sewing-machine (Fig. 102), the wringer, the vacuum cleaner,

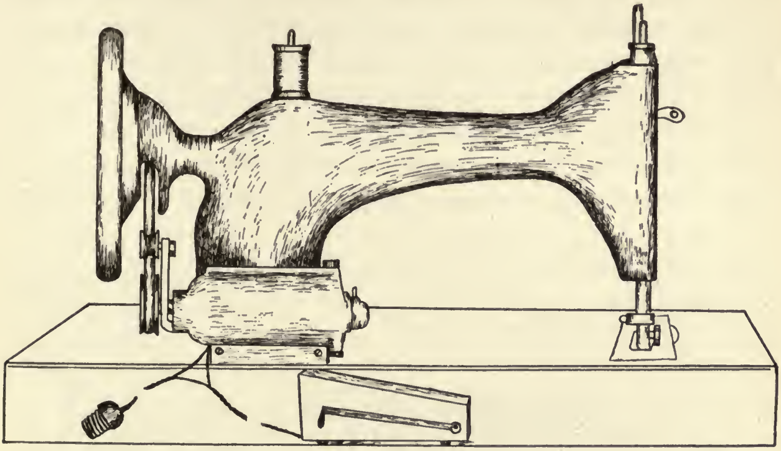


Fig. 102.—The motor on a sewing machine. The light machine stands on any table. The wires to the motor come from an ordinary electric-light socket, running through a control switch operated by the foot. This switch is here shown beside the machine.

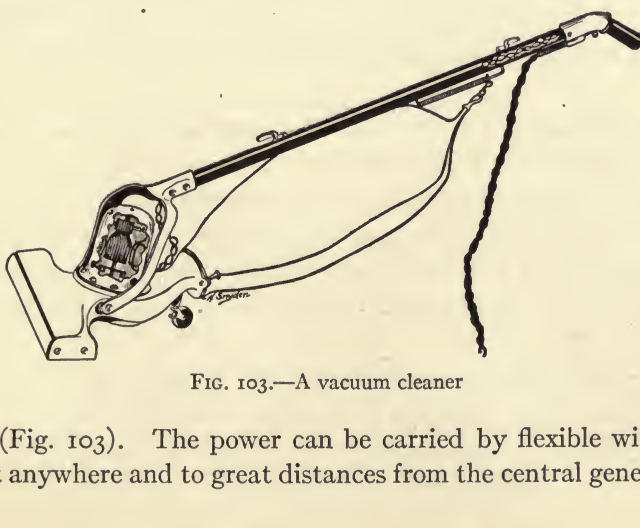


Fig. 103.—A vacuum cleaner

etc. (Fig. 103). The power can be carried by flexible wires almost anywhere and to great distances from the central generating

station. All sizes of motors can be built, from those of a fraction of one horse-power to those of thousands of horse-power. They can, therefore, be used for the most delicate operations, such as running the dentist's drill, as well as for tasks requiring tremendous power, such as the operation of electric trains (Fig. 104). The power is generated so as to produce continuous rotation rather than a back-and-forth motion which, as in the piston rod of an engine, must be transformed into rotation at a considerable loss of energy. Therefore, very high rotary speeds

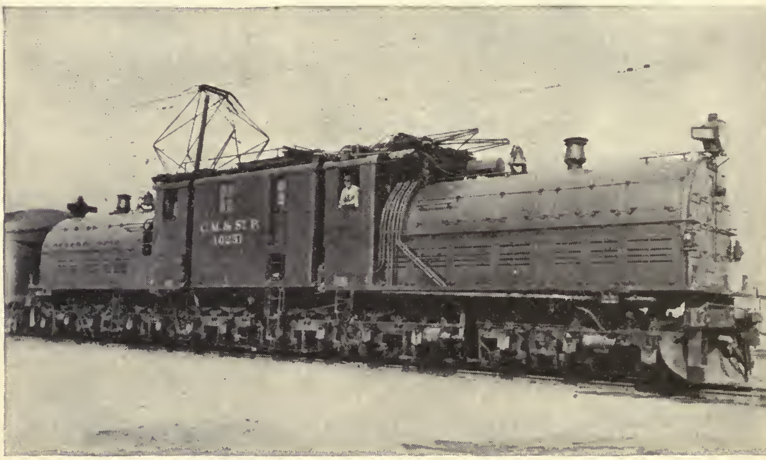


FIG. 104.—Electric locomotive, weight 265 tons, used on the Chicago, Milwaukee, and St. Paul Railway over the Cascade Mountains. (Courtesy of the Chicago, Milwaukee & St. Paul Railway.)

may be achieved. The motor of a rapidly running automobile makes a thousand or more revolutions per minute, while motors built especially for speed, such as those used on drills, centrifugal pumps, etc., may run at rates ten, twenty, or more times as great.

Faraday, it will be recalled, reasoned that if a current moving in a wire will cause motion in a nearby magnetic needle, then a moving magnet should produce a current in a nearby wire. He verified this hypothesis by introducing a bar magnet into a coil

of wire. It will be remembered that it was only when the magnet was moving that a current was produced; only, in other words, when the wire was cutting through the lines of force of the magnetic field. The current moved in the wire in one direction when the magnet was being introduced into the coil, and in a reverse direction when the magnet was being withdrawn from the coil. This principle is the basis of the dynamo.

If the armature of a motor is forced to revolve by sending a current through its wires, it might be expected that a current would be generated in the wires by the rapid mechanical revolution of the armature. This is true. If the magnetic field in which the armature revolves is produced by permanent magnets, the machine is called a magneto; if the magnetic field is produced by electric magnets, the machine is called a dynamo.

Let us follow in detail the events that would happen if the armature in a motor were revolved mechanically (Fig. 101). Such revolutions may be accomplished by a steam engine, a water wheel, a windmill, or by hand. As the upper of the three coils turns so as to approach the north pole of the magnet, it cuts through the lines of force of the magnetic field, and a current is produced in its wire. Since the current flowing through the wire in a clockwise direction produced a motion of this coil toward the north pole of the electromagnet when the machine was operating as a motor, therefore motion of the coil toward this north pole will now produce a current flowing in the wire in a clockwise direction. Or to state the matter in a slightly different way: The free end of the core *a* tends to become a south pole of an induced magnet as it approaches the north pole of the electromagnet, and the current in the wire must similarly tend to make this end of the coil a south magnetic pole. The current so induced now flows through the coil to the armature strips and thence through the spring clips and binding-posts, coming from the machine at *e*. But now *b* is moving away from the north pole, is becoming less strongly a south pole, and so the current in the coil about the core whose free end is *b* is flowing in an

anticlockwise direction. But since the strips on the armature are in the reverse position from those of the coil about the core whose free end is *a*, the current will flow from the machine in the same direction as in the first case. The coil about the core whose free end is *c* is now turning into the position occupied at first by the coil about the core whose free end is *a*, and so the process continues. Such a dynamo, therefore, gives rise to a direct current. The core of the electromagnet remains magnetized sufficiently while the dynamo is idle to start the process described when it is again used, and then its power is increased by the current generated.

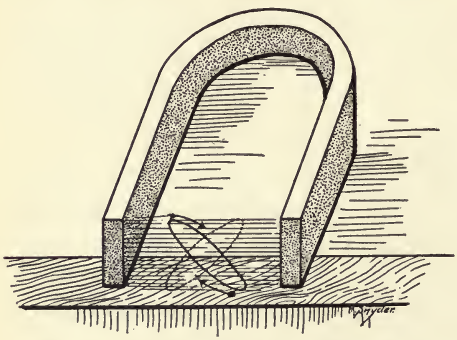


Fig. 105.—Diagram of a simple dynamo

If a current is moving along a circular loop of wire in the direction indicated by the arrow (Fig. 105), the south pole of its magnetic field is at the left of the loop, the north pole at the right. Recall the figure of the swimmer. If now the loop without a current in it were rotated between the poles of a magnet in a clockwise direction, the position previously occupied by the south pole of the loop is approaching the north pole of the magnet. The current generated in the wire will flow in such a direction as would produce a south pole in this position if a current were flowing: in other words, so as to develop a pole opposite in character to the one which the wire is approaching. Or you may use the "rule of thumb" to determine the direction of the flow of the induced current. Hold the thumb and the extended index and middle fingers of the left hand at right angles to each other. Point the index finger in the direction of the lines of magnetic force, the middle finger in the direction of the move-

ment of the wire through the magnetic field. Then the thumb held parallel to this wire will point in the direction of the flow of the induced current. If, however, the same wire is considered in the position indicated by the dotted line, the position of the south pole is moving away from the north pole of the magnet, and so the current in the loop is reversed. Rapidly rotating such a loop would therefore produce an alternating current in the wires connecting with its ends.

Or suppose the armature of a dynamo is a wheel having a number of cored coils set like cogs on its rim (Fig. 106). The wire of the coils is continuous and wound in each coil in the same direction. The two ends of the wire each run to a circular metallic band fixed to the axle of the armature. The current generated is taken from these bands by spring clips that are in contact with them. If such a wheel revolves with its rim inside of a circle of north magnetic poles, every time a coil approaches a pole it produces a current in one direction, and as it leaves the pole it produces a current in the opposite direction. This type of dynamo therefore generates on alternating current.

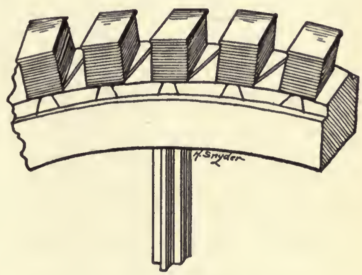


Fig. 106.—A dynamo with cored coils set like cogs.

When electric power is sent a long distance over wires from a central generating plant to neighboring cities for running their lights or factories, it is sent at high pressure. A long wire offers much resistance, and it is found that less power is lost in leakage to the air and to objects on the way when the current sent is of high voltage. We have become familiar with these high-power lines, as the distribution of electrical power has become common (Fig. 107). The wires are usually supported on steel towers, and huge porcelain insulators are used instead of the small glass ones familiar on telegraph and telephone lines, which carry cur-

rents of low voltage. Commonly, too, when the lines cross highways, the towers bear signs to the effect that the wires are dangerous. A shock produced by contact with a low-voltage current usually causes surprise and more or less discomfort, but

FIG. 107.—A high-power transmission line

death is often the result of shock from a high-voltage current. In case of severe shock the means of resuscitation are the same as in the case of drowning, namely, the maintenance of artificial respiration and of the body temperature.

It is usually unsafe as well as undesirable from a mechanical point of view to use a high-voltage current for ordinary purposes

until it is "stepped down" to a lower voltage by a transformer. One type of transformer easily comprehended may be briefly described. A fine insulated wire is wound many times around a small cylinder of soft iron outside of which is a larger cylindrical frame wrapped with a few turns of coarse insulated wire. When an alternating current of high voltage is sent through the inner coil, it induces a low-voltage current of greater amperage in the coarse wire. Thus a current of 5,000 volts and 1 ampere might be stepped down to one of 100 volts and 50 amperes. Conversely, if an alternating current of low voltage is sent through an inner coil of coarse wire it will induce a high-voltage current of proportionately less amperage in the fine wire of an outer coil. In the latter case the transformer is built to step up the current.

When the transformer is used on a continuous current it is provided with an interrupter, one type of which is similar to the device used to rapidly make and break the current of an electric bell. For it is only when the moving lines of magnetic force produced by one coil cut the wires of the other coil that a current is produced in this second coil. This occurs incessantly with an alternating current since the direction of the flow is constantly changing; it is assured in a constant current by the use of the interrupter.

It was not until the invention of the dynamo made it possible to produce electricity cheaply and abundantly that motors, electric lights, electric heaters, and similar contrivances became commonplace.

When an electric current is forced under high voltage through a fine wire, the electric energy is partly transformed into heat energy. If you send a current from a dry battery through a fine copper wire, you will feel the wire become hot, or if you wrap the wire several times about the bulb of a thermometer, it will very soon register a rise in temperature. The incandescent electric light is made by sending a current through such a fine resistant wire that a strong glow of light is the result. In the earlier types of electric lights a fine filament of carbon was used in place of a wire. Since carbon heated to the glowing point in

the air would promptly combine with oxygen or burn, it was necessary to exhaust the air from the electric-light bulb or to fill the bulb with some gas like nitrogen or argon that does not unite with carbon.

It was an American, W. Starr, who in 1844 invented the first incandescent lamp. A thin strip of carbon in a glass capsule from which the air had been exhausted produced a light as the carbon glowed with the current sent through it. The next year a Frenchman, De Changy, used lamps with filaments of platinum for lighting the workings in coal mines. Progress was gradually made, but the incandescent lamp remained a crude affair until Edison worked on it in 1878, when he made so many improvements that he is looked upon as its real inventor. He used a carbonized fiber of bamboo which was attached to platinum wires so fused into the glass of the bulb that the latter could be made sufficiently air-tight to hold the vacuum for a long time. Recently, in place of the carbon, filaments of metals like tantalium or tungsten are used. Rare ores are made to yield these metals, and the invention of methods for making them malleable and ductile was very difficult. This task was necessary, however, as naturally these metals are very brittle and fragile. But now a single pound of tungsten makes 30 miles of filament that stands a temperature of 5,000° F. A carbon filament could not stand even half the temperature necessary to produce the more intense incandescence of the wire (Fig. 108).

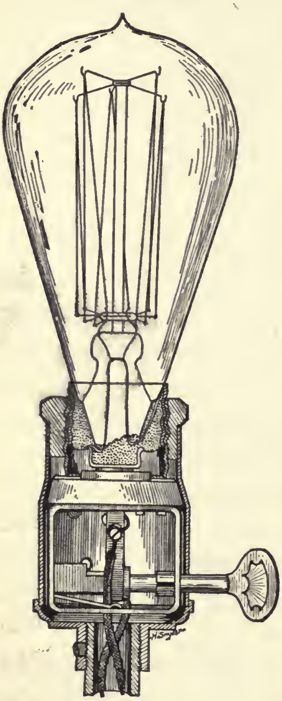


FIG. 108.—Diagram of an electric light.

In wiring a house for electric lighting, it is customary to connect the lamps in parallel rather than in series as the latter method would offer more resistance, since all the current must then go through each fine filament (Fig. 109). When the lights are connected in parallel, the current flows through all the filaments simultaneously, which is equivalent to being carried in one wire as many times as large as one filament as there are lamps.

The current goes to the several lamps through wires that connect with a fuse in a fuse box. The fuse is merely a strip of some easily melted alloy inclosed in a tube or porcelain box. If through the accidental crossing of wires an unduly strong current should be sent into the light circuit, this strip or fuse would become hot, melt, and so sever the connections before enough heat could be generated in the wiring of the house to start fires in the woodwork along which the wires might be laid.

In the arc light the current is made to flow through two carbon pencils whose tips are opposed at a slight distance from each other. As the current jumps this space it carries with it numerous highly incandescent particles from the positive to the negative carbon and so produces the arc. The tip of the positive carbon is, therefore, always hollowed while the negative is always pointed.

The temperature of the glowing tip of the positive carbon is about 6,000° F. Such temperature makes the electric furnace possible. A crucible of heat-resistant substance is fitted about the ends of a pair of large carbons adjusted like those of the arc light. A heavy current sent through the carbons melts exceedingly refractory substances placed in the crucible. Carbon so melted under high pressure forms artificial diamonds.

In electric heat devices of various sorts, e.g., the heater, the toaster, the percolator, the curling-iron heater, the bed pad, the flatiron, etc. (Fig. 110), the current is sent through coils of wire or metallic plates that become more or less heated according to their resistance and the strength of the current.

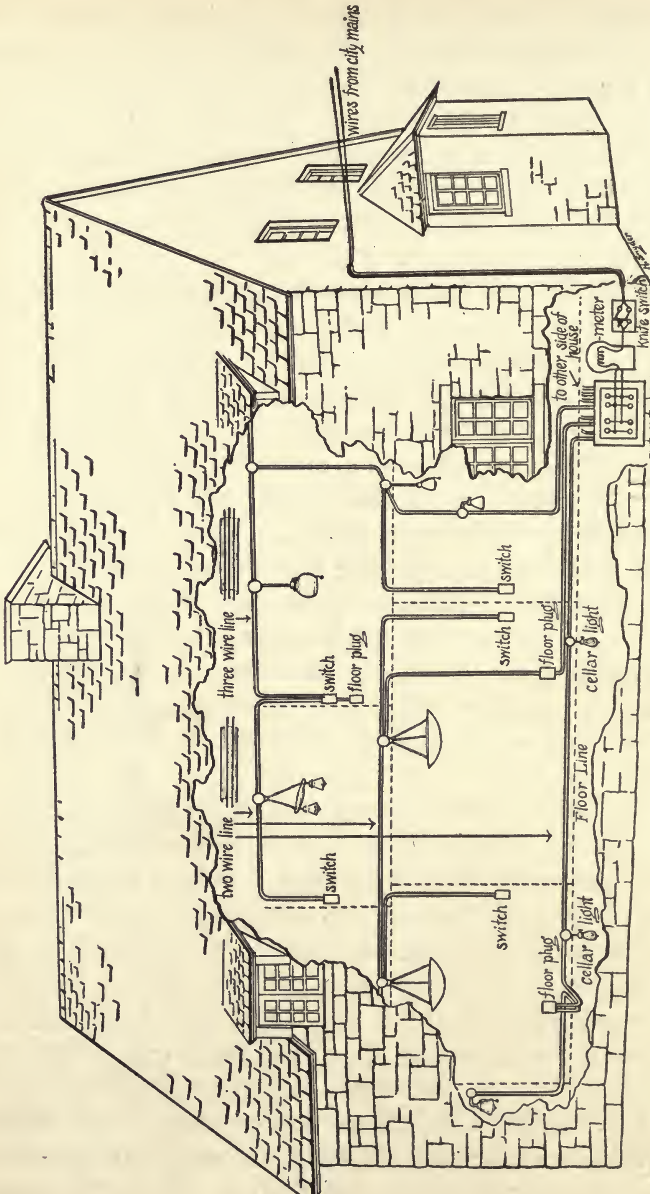


FIG. 109.—Diagram of a house showing wiring for electric lights

As far as the principle of operation is concerned, such devices can be readily understood from the diagrams of Figure 110.

FIG. 110.—(*a*) An electric heater; (*b*) an electric percolator sectioned to show inside; (*c*) an electric flatiron, showing diagram of inside; (*d*) an electric toaster.

In the toaster, for instance, the current going through the wires on the frame causes them to become red hot. The slice of bread on the rack is exposed to their heat and so is toasted.

CHAPTER XI

RADIO COMMUNICATION[1]

There's music in the air.
—G. F. Root.

All of the inventions of electrical appliances described above that have succeeded one another with such rapidity have been marvelous, but no other one has so taken hold of the popular interest as has wireless or radio. It has seemed incredible and little short of the supernatural, yet it is quite simple and easily comprehensible as science now explains it.

Transmission of telegraphic and telephonic messages by radio is accomplished by setting up in the ether an electrical wave motion, which, when intercepted by a suitable receiving apparatus, will in turn set this receiving apparatus into vibration similar to the electrical vibration of the transmitting station. Thus the original dots and dashes or the speech or musical sounds originating at the sending station may be reproduced at the receiving station, sometimes many thousands of miles distant. The ether is a highly elastic medium that is supposed to fill space.

It must be understood that the actual vibrations in the ether of the space separating the stations are inaudible, and produce sound only after they have set the apparatus of the receiving station into vibration and these electrical vibrations have been converted into less rapid vibrations that produce sound or leave a permanent record, as in the case of automatic recorders.

Since the whole system of radio transmission depends on wave motion in an elastic medium, it can be compared with other wave motions which are more familiar. Recall how a stone thrown into a quiet pond starts a series of waves that in ever

[1] This chapter has been prepared by Fred G. Anibal, formerly radio officer, U.S. Air Service.

widening circles run to the shore of the pond, and there set to rocking the weeds or grasses that are growing along shore. A bell when set in vibration will cause the surrounding air to be set in motion, and this wave motion when it strikes the ear will set up there a similar vibration which is transformed to nervous impulse and transmitted to the brain, so we hear the sound (Fig. 166, p. 327).

Sometimes it has been noticed that certain notes struck on a piano will cause objects in a room to vibrate; other notes will seem to have no effect on these same objects. Thus, if a violin string be tuned so it gives off the C note if bowed and this note be struck on the piano, the violin in the same room will be found to also sound this note faintly. The violin string is set in motion because the sound waves regularly striking it have the same period of vibration as is now natural to it, and so gradually produce in it the same rate of vibration as the vibrating wire originally struck in the piano. The violin is said to be "in tune" with the note, and so will respond to notes of this rate of vibration. Similarly, the radio receiving apparatus must be adjusted so as to be "in tune" with the sending station. This adjustment may be changed so that, although many stations may be sending out vibrations at the same time, only the one with which the receiving apparatus is "in tune" will produce noticeable effects. Sending stations are also capable of adjustment so that at different times they may send out vibrations of different rates.

Radio apparatus then consists of two types of appliances: those that create the waves, the large transmitting and broadcasting stations, and the appliances which receive the waves, or the many thousands of small receiving sets distributed over the country.

The sending station consists of apparatus which will produce electrical vibrations of such high frequency that they will set the ether into vibration, and thus radiate through space in every direction from a point. Hence the expression "radio broadcasting." A system of control must also be included so that the

series of vibrations may either be broken into long and short groups, as with the wireless telegraph when transmitting dashes and dots, or modifications made in the nature of the wave so that sounds of various pitch may be transmitted as in the case of the radio telephone.

A very simple amateur wireless telegraph sending outfit may consist of a source of electrical power, such as a battery,

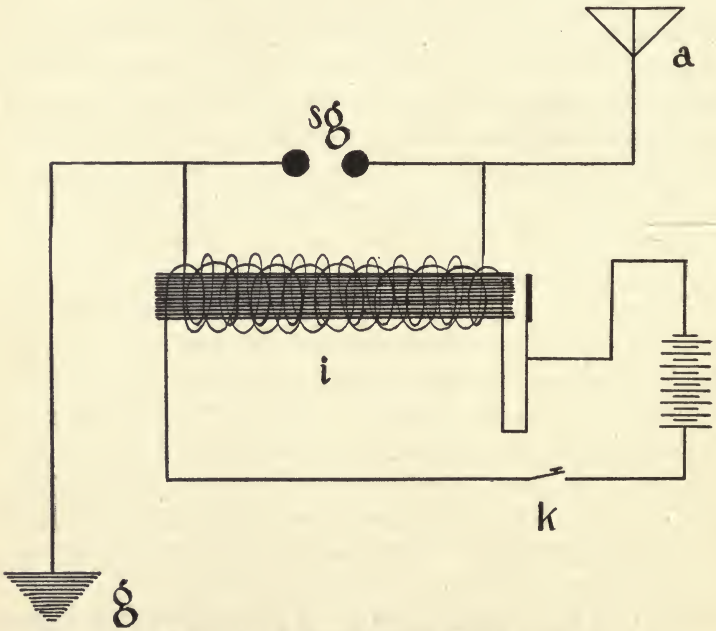


FIG. 111.—A simple wireless sending outfit

a key for controlling the power, an induction coil and spark gap by means of which the battery current is transformed into high-frequency electrical current, and an antenna or electrical conductor extending some distance above the earth, so that the electric waves may readily radiate into the ether with little interference. Such an arrangement is shown by diagram in Figure 111. The source of electrical power is shown at (*b*), and consists of a battery of several cells. The key for interrupting

the primary circuit is shown at (k). An induction coil and spark gap for transforming the low-voltage direct current into a high-voltage, high-frequency oscillating current are shown at (i) and (sg). The antenna or aerial conductor is shown at (a) and the other side of the spark gap is grounded at (g).

When the primary circuit is closed, sparks will jump across the gap (Fig. 112), and since these are in reality electrical discharges of very high frequency they will set up in the antenna and ground circuit a very high frequency electrical current. This current will set the ether surrounding the antenna into vibration, and thus will radiate into space long and short series of vibrations corresponding to the dots and dashes of the telegraph code.

It is in the circuit consisting of antenna, spark gap, and ground connections that the radio vibrations originate. A condenser which will withstand high potential electrical

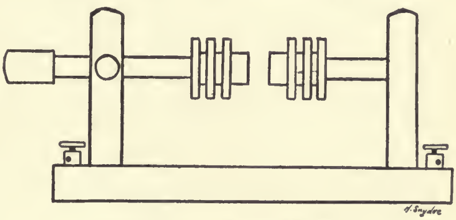


FIG. 112.—A spark gap

charges of several thousand volts may be connected across the spark gap, and then a coil of heavy wire with adjustable connectors may be included in the antenna circuit. With these additions we have a typical radio-frequency oscillating circuit as is shown in the second diagram (Fig. 113, p. 254).

The condenser consists of two sets of sheets of tinfoil or other good conductor, the sheets of one set alternating with those of the other, and each sheet is carefully insulated from its adjacent fellows. The ends of the fine wire on the transformer each attach to one of these two sets. One set also fastens to a wire that runs to the aerial, and that also branches to connect with one of the metallic knobs of the spark gap; the other set fastens to a wire that runs to the ground, and that branches to the other knob of the spark gap. This spark gap is made of two adjustable metallic rods, mounted close together in the same straight line. Each

rod bears at the end opposite its fellow a metallic knob; these knobs, by the adjustment of the rods, may be spaced as desired.

As a current flows in the coarse wire of the induction coil, it induces a high-tension current in the fine wire coil. Electrons then discharge on to one set of sheets of foil in the condenser, say the set connected with the aerial. These repel similar charges

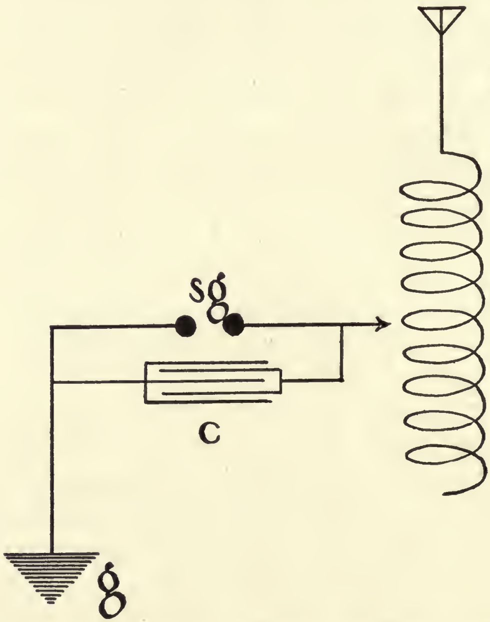


FIG. 113.—Diagram of a more complex sending outfit

on the other set of sheets, and drive them off at the same time they draw up positive charges from the earth on to them. Such positive charges help hold more electrons on the first set which draw more positive charges to the second set. This "condensation" continues until a strong charge of high-voltage electricity accumulates, when finally there is a discharge back and forth across the gap, and simultaneously the current surges up into the antenna and sets going radio waves in the ether.

The rate of frequency of the vibrations set up in this circuit depends essentially on two factors, capacity and inductance. The condenser furnishes the capacity, and the number of turns used in the helix (coil) of the antenna circuit determines the inductance. As we increase the number of turns of the helix included in the antenna circuit, the greater inductance makes the condenser accumulate a heavier charge before the discharge occurs, so the intervals between discharges are longer and the waves created are therefore longer. This arrangement makes it possible to tune the sending station within limits depending upon the size of the induction coil, condenser, length and height of antenna, etc. Usually small amateur stations are tuned so as to have the maximum output of energy from the antenna within government frequency regulations for amateur stations.

The electrical vibrations which actually occur in the oscillating circuit and which are radiated into the ether from the antenna are really a series of wave-trains. The more numerous the waves are in each wave-train, the shorter each wave is; or the greater the frequency, the shorter the wave-length. This frequency is very high in radio waves, ranging from ten thousand up to several million per second, and is known as radio frequency. Since the waves travel in ether with the speed of light, or 300,000,000 meters per second, we can easily determine the wave-length of a sending station if we compute the frequency from the capacitance and inductance values. Thus a frequency of 730 kilo-cycles (730,000) would have a wave-length of about 411 meters.

The rate at which the wave-trains succeed each other is much lower than radio-frequency rates, and is within the range of audio frequencies or the rate of vibration of sound waves, usually around 500 to 1,000 cycles per second. The pitch or note of the incoming wave from a damped wave-sending station depends on the frequency of the wave-trains. Damped waves are those that gradually die out like the waves of a wave-train (Fig. 114). For comparison a standard A tuning fork vibrates 435 times per second.

The simple wireless receiving equipment consists of appliances for intercepting these trains of high-frequency ether waves and converting them into electrical vibrations which can be made to produce mechanical vibrations of audible frequency in a telephone receiver.

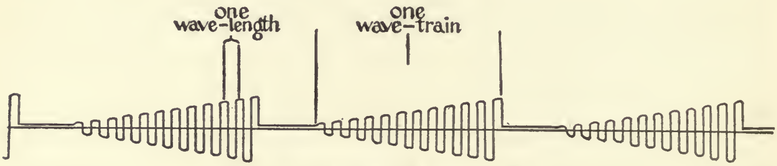


FIG. 114.—A train of damped waves

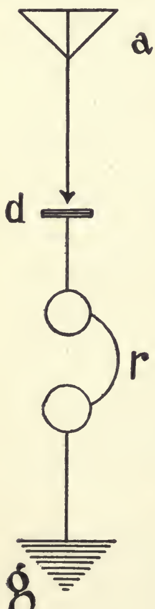


FIG. 115.—Diagram of a simple receiving set.

A simple wireless receiving outfit may consist of (Fig. 115), (*a*) the antenna for receiving the ether waves, (*d*) a detector for converting these waves into electrical impulses of audio frequency, (*r*) a telephone receiver for converting the electrical impulses into mechanical vibrations, and (*g*) a ground connection.

The receiving antenna is not necessarily so large as the sending antenna, and may consist of a single wire suspended between high points above surrounding buildings or trees and about 1,000 feet in length. Much simpler antennas have been found to be very successful. Wires suspended in an attic are sometimes employed, and even small loops of wire within a room are very efficient with sensitive receiving equipment. Even bed springs and fire escapes give fair results when not many miles from the sending station.

The detector is the distinctive part of the radio-receiving circuit. There are a great number of types of detectors. They all consist of an arrangement whereby the electrical oscillations are rectified or made to flow principally in one direction with the result that a pulsating current of audio frequency flows through

the telephone receiver. The commonest type of detector in use is the crystal detector. This piece of apparatus consists of a piece of mineral, usually galena or iron pyrites imbedded in a fusible alloy and so mounted that a fine wire may be adjusted to touch the surface at one point. Since some points on the mineral are more sensitive than others, the wire is made adjustable so that a sensitive point may be easily found while trying to pick up signals caught by the antenna (Fig. 116).

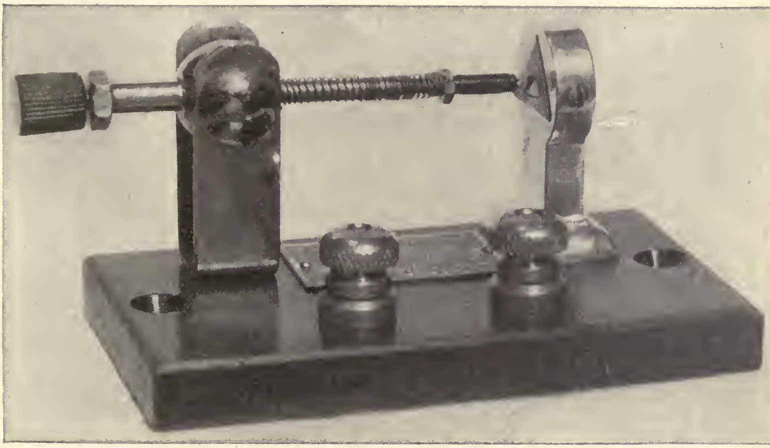


FIG. 116.—The crystal detector. (Photo by the Radio Corporation of America.)

The action of this crystal type of detector as a rectifier is much the same as that of a check valve in a pump. When the oscillating current from the antenna, which is a back-and-forth surge, attempts to pass through the crystal from the wire point, the back-surge may be stopped so that current in one direction only will pass through to the telephone receiver, and so on to the ground, completing the circuit. The effect is that of a pulsating direct current of audio frequency which will produce one click in the telephone receiver for each wave-train. Since a dot in the telegraph code is a short series of wave-trains, it will be reproduced in the telephone receiver by a short succession of

clicks at audio frequency, producing a short buzz. A dash will be a long buzz.

The telephone receiver usually employed consists of two watch-case receivers mounted on a head band in such a manner that one receiver will be pressed on each ear. Such a piece of equipment is called the head set (Fig. 117). The ordinary tele-

FIG. 117.—Radio room of the SS. "Leviathan." (Courtesy of the Radio Corporation of America.)

phone receiver is not sensitive enough for the faint radio signals, and, therefore, much more sensitive receivers with very thin diaphragms and a resistance of around 1,500 ohms are employed.

In order that signals of different frequencies may be picked up, the receiving equipment must include apparatus for varying the inductance and capacity of the circuit. By variation, the receiving circuit may be tuned to respond to the vibrations of the sending station. It will be recalled that the violin in the

room with the piano will vibrate only when a certain note is sounded. The receiving circuit can be adjusted by changing the values of capacity and inductance, so that it will respond to any frequency or wave-length desired. The reception will

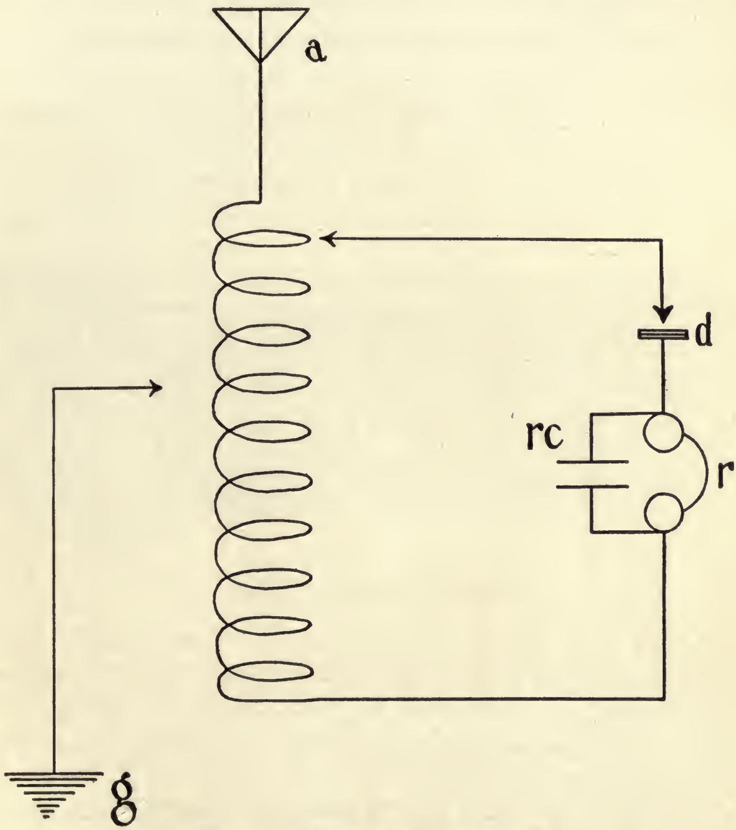


FIG. 118.—A simple receiving circuit

not be interfered with by waves sent from other stations operating unless the wave from such stations is at the same frequency as the wave sought to be intercepted. A very simple receiving circuit that may be tuned by varying inductance only while the capacity is fixed is shown by the diagram in Figure 118. This

circuit shows the type commonly employed on simple receiving circuits, and is in reality two circuits. This method of connection does not introduce the resistance of the head set into the antenna circuit, and permits the vibrations from the antenna to flow more freely.

The tuning coil (*l*) consists of one layer of insulated wire (about No. 20) on a cardboard tube about 5 or 6 inches long (Fig. 119). The insulation is removed in two strips on opposite sides of the coil to permit connection by a slider which touches one turn of wire at a time. In this manner the number of turns of wire between the antenna and the ground can be varied by moving

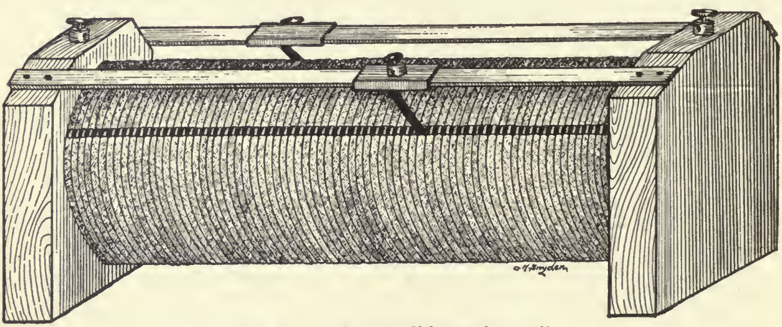


FIG. 119.—A two-slide tuning coil

the slider. The turns of wire themselves constitute the condenser in this case so that the capacity is also varied when the slider is moved. This circuit from the antenna (*a*) (Fig. 118) through the turns of the tuning coil (*l*) to the ground (*g*) constitutes the primary circuit.

The secondary circuit uses the same coil but a different portion of it, part of which may overlap the primary inductance, as shown in the diagram. This closed circuit is from the second slider on the tuning coil (*l*) through the detector (*d*), through the phones (*r*), and back to the other end of the tuning coil.

By moving these sliders we can change the inductance in both the primary and secondary circuits, and thus place the receiving outfit in tune or in electrical resonance with the send-

ing station from which the signals are desired. When one tuning coil is used with two sliders in this manner, and so becomes a part of two circuits, it is known as an auto-transformer. In tuning such an outfit the primary circuit or open oscillating circuit must be tuned to respond to the frequency of the sending station, and then the secondary or closed oscillating circuit must be tuned to the primary circuit. Sometimes a small fixed condenser is shunted across the phones, permitting the vibrations to flow more easily. This is known as the phone condenser, and has a capacity usually of about .001 microfarads. This condenser (*rc*) is sometimes left out of the circuit, and in such case the phone cords themselves act as a condenser.

A simple receiving set such as the one described, but equipped with a simple tuning coil, may easily be made and assembled as follows. For the tuning coil procure a cardboard tube about five or six inches long and three and a half to four inches in diameter. Round cardboard oatmeal boxes serve this purpose very well. This tube is to be wound with insulated wire and mounted horizontally on a board, which may serve also as the base for the detector and the terminals for the phone connection.

For the base secure a piece of material, wood or fiber, about two inches wider than the diameter of the tube and four or five inches longer than the tube. The tube is provided with end pieces of the same material as the base. These end blocks are to be cut one inch less in width than the base board, of a height equal to the width of the base board. In each end piece is now cut a shallow groove to receive the ends of the cardboard tube. This groove should be the same distance from the top of the end piece as from the sides. The guides for the sliders and the sliders themselves for the tuning coil may be secured cheaply at any radio supply shop or ten-cent store. The guide rods should be of square metal material of $\frac{3}{8}$- to $\frac{1}{2}$-inch stuff. They must be as long as the length of the tube and end pieces when the tube is fitted into the grooves in the end pieces. The sliders are small blocks of wood with a square notch cut on one side to fit snugly over the

slider guide. A piece of metal, brass or copper, is tacked or screwed on the under side of the block to hold it in place on the guide rod. This piece of metal should be cut with a narrow strip which may be bent down and then back under the slider so that it makes spring contact with the turns of wire on the cardboard tube. In order that contact may be made successively with each turn of wire on the tube, the insulation must be scraped off in a narrow strip extending the full length of the tube, directly under each slider rod. The pressure of this sliding contact on the wire must be strong enough to insure positive connection between slider and each separate turn, but not so strong as to wear the wire rapidly or to require much force to move it along the slider. Contact with the slider rod is made by the metal covering over the groove on the slider. The end of this metal piece may be cut slightly so that it can be pressed tightly against the guide rod.

Two of these sliders with guide rods are to be provided. One is to be mounted directly over the tube with the ends of the rod secured to the end pieces. Square notches may be cut in the end pieces and the rod fitted snugly into these and secured by a screw at one end through a hole in the rod, and by a binding-post at the other to which the connection may be made. The slider rod is to be mounted at the side of the tube and directly over the center.

The winding on the tube is to be of No. 22 insulated wire. Enameled wire may be used. First shellac the tube. Punch two holes in the tube about a quarter of an inch apart and one half-inch from one end. Pass about ten inches of wire through one hole from the outside and then secure it by bringing it up through the other hole and then again through the first hole and back out through the second hole. Now wind the wire closely and smoothly over the tube to within about half an inch of the other end. Secure the wire on the same side of the tube and in the same way as before, allowing about ten inches for connection. To hold the wire in place, a second coat of shellac may now be applied.

Before the tube is mounted on the base, the detector should be procured or made, and provision made for the phone terminals at one end of the base, and for the binding-post for the ground connection on the other end of base (Fig. 119).

It is suggested that a crystal detector be purchased. This detector may be of the type that can be adjusted or one that is always in adjustment. If it is desired that the detector be made, it would be well to investigate various devices on the market and duplicate one of the numerous types. Essentially the detector merely consists of a small crystal of selected galena or iron pyrites, which is touched with light pressure by a small spring wire known as a "cat whisker." One connection is made to the whisker and the other to the crystal. The crystal may be imbedded in fusible alloy, and secured to the base board with screws. A binding-post may be set in the base close to the crystal, and the whisker secured to the binding-post in such a manner that it loops over with its point resting lightly on the surface of the crystal.

A small radio-phone condenser should be purchased and mounted at one end of the base between two binding-posts provided with holes to take the terminals of the cord leading to the phones. The spacing of these binding-posts is determined by the phone condenser, which is a small strip with holes in each end for the binding-posts.

The set is now ready to be mounted on the base board and connected up. As small holes are to be drilled in the base board for the connecting wires, it is advisable to assemble the set first in order to determine the position of these holes before securing the parts permanently.

The tuning coil is mounted at one end of the base with the end piece one inch from the end of the base and one-half inch from each edge of the base. Wire finishing nails may be used to secure the end pieces of the coil to the base board. The tube with its layer of wire is glued into the grooves with the ends of the winding down. These ends are threaded through holes previously drilled

through the base board. The wire nearest the end of the base is fitted into a groove made on the under side of the base and securely connected to the binding-post set in the center of this end of the base. This binding-post receives the ground connection.

The other end of the winding is also led through a hole in the base and along a groove to the under side of the binding-post which carries the cat whisker of the detector. Another style of connection, which may work better in some localities, is that of leaving this end of the coil unconnected, and connecting this side of the detector directly to the ground binding-post.

The detector is mounted midway between the end of the coil and the binding-posts for the phones. These phone connections are placed close to the end of the base and midway between the sides so that the strip condenser will be parallel to the end of the base. One of these phone terminals is connected to the crystal of the detector and the other to the slider mounted on the side of the coil. The connection wire is to be led through a groove on the under side of the base to a hole directly under the binding-post on the slider rod. The slider rod on the slide is then secured to the ends of the tuning coil on its front side by means of the binding-post in such manner that this binding-post will be on the end nearest the detector. The other slider rod is mounted on top of the coil with its binding-post on the other coil end. This slider is connected to the aerial wire or antenna.

The phones must be purchased. They may be either single or double. A double head set of 2,000 ohms resistance is recommended. When the phone cords are connected to the binding-posts provided, the set is ready for operation as soon as the antenna and ground are connected.

The ground connection is made with a bare copper wire (about No. 10 or No. 12) to a water-pipe or to a metal plate buried about three or four feet in the earth. If the earth is very dry this plate may have to be buried deeper.

The antenna is made and installed as follows. First decide upon its location. The wire should be suspended between two high points so that it does not come in contact with anything between these points. The wire should be stranded if possible and as nearly 150 feet long as the location will permit. Attach to the end of this stranded wire, near that insulator which is closest the set, an insulated wire which is led through a tube insulator into the room where the set is located. Around the groove in the knob insulator, or to the other end of the strain insulator, attach wires or ropes and secure these to the high points selected. For these points poles may be erected on the roof of a building, or trees may be used. The antenna need be only high enough to clear immediately surrounding obstacles.

To adjust the set for receiving, fit the receivers to the ears and adjust the whisker on the detector so that it just touches the crystal lightly. Now move the sliders back and forth one at a time until locations are found at which the signals are heard. After a little practice the proper positions of the sliders will be more readily located and it will be possible to adjust the detector with greater nicety.

A more elaborate and yet very simple receiving outfit is shown in Figure 120 (p. 266). The difference between this outfit and the one in Figure 118 is found in the substitution of a receiving transformer in place of the tuning coil and the addition of a variable condenser. The receiving transformer consists of two cardboard tubes each wound with a single layer of wire and adjusted so that one will slide within the other. The wire on both tubes is the same size. When a current flows in the circuit from antenna to ground going through the outer coil, it induces a current in the other coil whose strength depends on how far the second coil is shoved into the first. The variable condenser (Fig. 121) consists of two sets of metal plates, those of one set alternating with and parallel to those of the other, to which they lie very close without being in contact. One set, the rotor, is so mounted that its plates may be moved so as to lie wholly or

only partly between those of the other set. By adjusting the plates, the capacity can be varied and the natural vibration frequency of the primary circuit can be changed. This type of

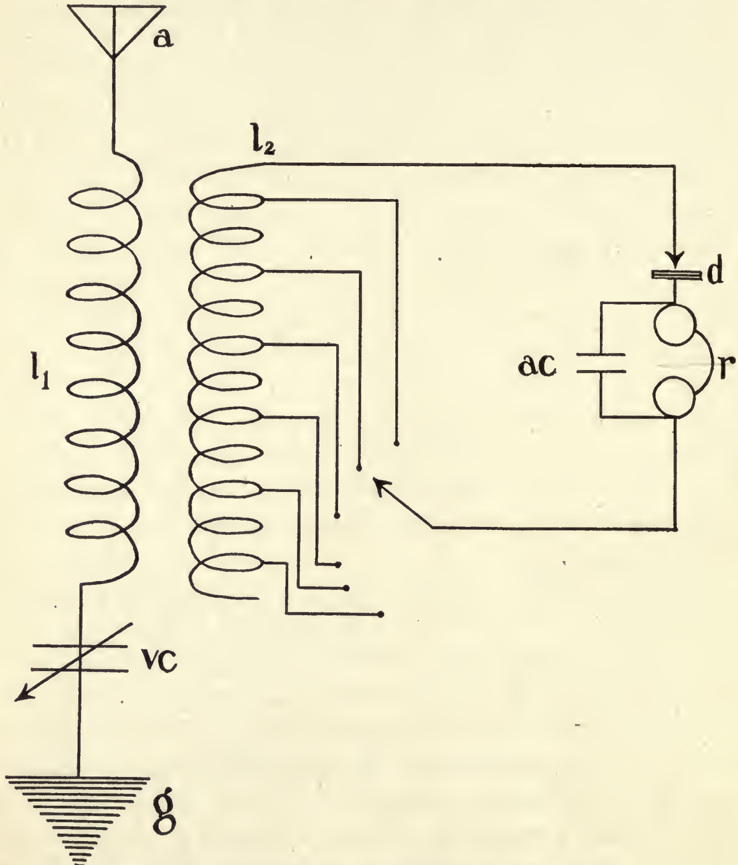


FIG. 120.—Diagram of a more elaborate receiving set

outfit permits much closer tuning than the outfit shown in Figure 119, and since the coupling is adjustable, more interference can be cut out.

Many large commercial wireless telegraph stations and ship stations still employ the same method of transmission of signals

as the simple wireless amateur station. Such sending stations are known as discontinuous wave stations because they radiate into the ether these series of wave-trains. In such large stations the source of power is usually an alternating current dynamo, and a high-frequency transformer is used in place of the induction coil. The helix may consist of many turns of heavy copper wire or rod, and the condenser usually is made up of many rows of large Leyden jars in parallel. (See *Field and Laboratory Guide in Physical Nature-Study*, p. 69.)

FIG. 121.—A rotary variable condenser.

The more modern method of radio transmission employs what is known as the continuous wave. As the name indicates, the wave motion which is radiated from the antenna is not broken into a series of wave-trains each of which dies out before the next begins. The continuous wave is one long series of waves of radio frequency, which are sustained, and have the same strength as long as the circuit at the sending station is closed. A simple diagram to illustrate this continuous wave in comparison with a discontinuous wave is shown in Figure 122.

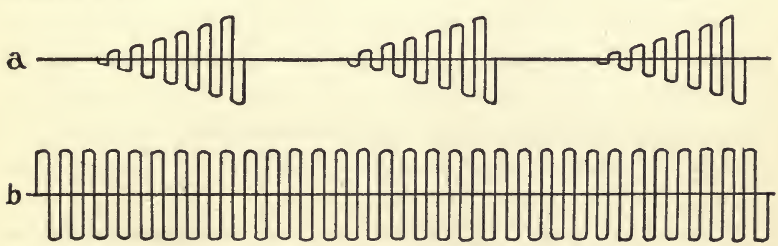


FIG. 122.—Discontinuous and continuous waves

The methods employed to produce these continuous waves are of various sorts. Sometimes an arc between a carbon and a copper electrode is used. The arc is placed in a circuit with inductance and capacity, and when properly balanced such a circuit will

oscillate at radio frequency and send out on the antenna a continuous wave. Sometimes the dynamo itself is a radio-frequency alternator generating a current of such a large number of alternations or cycles per second that when connected in a circuit with suitable capacity and inductance it can be employed to produce directly oscillations of radio frequency.

Perhaps the most popular method of producing continuous waves for radio transmission is by means of the three-electrode vacuum valve. Since this piece of apparatus is also very generally used as a detector for radio reception, a very brief treatment of its construction and mode of operation will be given.

FIG. 123.—Three-electrode vacuum valve.

The vacuum tube or three-electrode vacuum valve (Fig. 123) depends upon the emission of a stream of electrons or particles of negative electricity from a hot wire or filament. In construction it is similar to an incandescent electric-light bulb. A wire filament is inclosed in a glass globe from which the air has been exhausted. In addition to the filament, which is counted as one of the three electrodes, there is also placed within the tube a metal plate. Between the plate and the filament is supported a grid or rack with many strands of wire stretched across much like a fence. This plate and grid constitute the other two electrodes. Both ends of the filament, the plate, and the grid lead to terminals outside the tube so that there are four connections to the three-electrode vacuum valve.

When used as a simple detector of damped waves, the three-electrode vacuum valve is connected into the receiving circuit as shown in the wiring diagram of Figure 124. It will be noted that this receiving circuit is practically the same as for the crystal detector circuit, and likewise consists of primary and secondary circuits. The additional feature is that the oscillating circuit is connected on one side of the variable condenser

to the grid of the vacuum valve and on the other side to the filament. The plate is then connected in a third circuit through a high-potential battery of about 40 volts, through the telephone receivers, and back to the filament.

The action is about as follows. When the filament is lighted by the current from the battery at *a*, which is controlled through

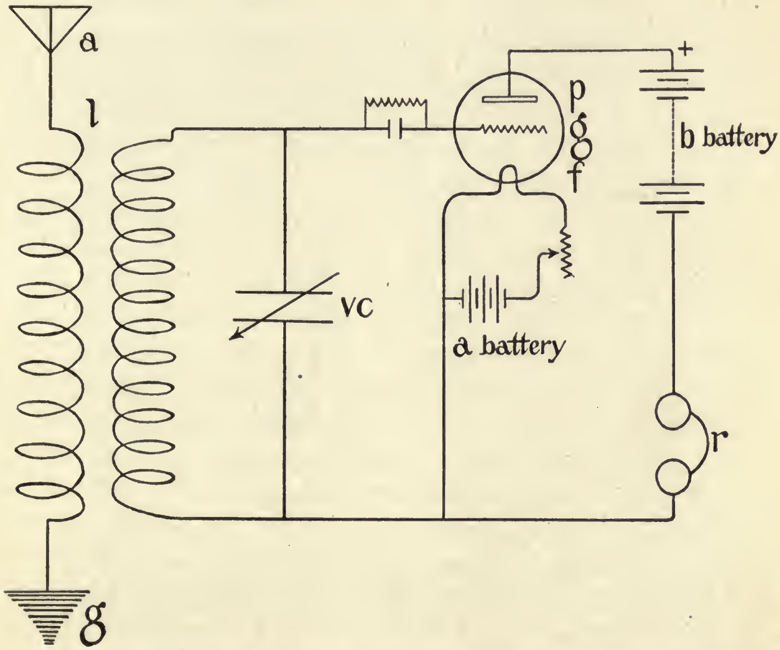


FIG. 124.—Diagram showing the use of the vacuum tube as a detector: (*a*) antenna; (*l*) receiving inductance; (*g*) ground; (*r*) head set; (*p*) plate in tube; (*g*) grid in tube; (*f*) filament in tube; (*vc*) variable condenser.

a rheostat, a stream of negative particles of electricity or electrons passes from it between the wires of a grid and strikes the plate, which is positively charged by the high-voltage battery. This stream of electrons constantly striking the plate will cause a current of electricity to flow through the plate circuit and through the telephone receivers. Any variation in this current, then, will produce an effect in the telephone receivers.

As long as the grid is neutral, the plate current is steady and direct. When the incoming signals set the receiving circuit into electrical vibration, the potential of the grid will change from positive to negative very rapidly as each wave-train passes. When the grid is negative it will repel the negative particles of electricity and so stop the flow of the plate current. The effect will be a pulsating current of audio frequency through the telephone receivers each time a wave-train affects the grid. Since slight changes in potential of the grid produce large changes in the current through the plate circuit, the vacuum tube is said to act as an electrical valve, allowing current to flow through the plate circuit in one direction only.

As was stated above, the vacuum tube is also used to produce continuous waves. Larger power tubes, of course, are used in the large continuous-wave transmitting stations. The tubes for this use bear the names of pliotrons, oscillions, or other names derived from characteristic features in their construction (Fig. 125). It has been shown that slight variations in the grid circuit of a tube produce large variations in the plate current. This action is made use of by causing the plate current to flow through an inductance placed close to a similar inductance in the grid circuit. When oscillations are started in the grid circuit they produce oscillations in the plate circuit which are "fed back" into the grid circuit through this inductive coupling of the grid and plate circuits. These inductances can be so adjusted that the oscillations will be sustained, and a continuous wave will be produced in the antenna circuit.

The reception of continuous wave signals cannot be accomplished with the ordinary rectifying detector. Although the incoming wave may be rectified and caused to pass through the telephone receivers, its frequency is so great that the diaphragm of the telephone receiver will not respond to it, and so some means must be introduced to produce a frequency of audible range in the telephone receiver. This production of audio-frequency vibrations in the telephone receiver is accomplished

by introducing into the receiving circuit a vacuum valve to act as a generator of continuous waves. When two tuning forks of slightly different pitch are sounded near together, a pulsating sound is heard. This is due to the sound waves reinforcing each other and interfering with each other at regular intervals. The number of pulsations per second will be equal to the difference

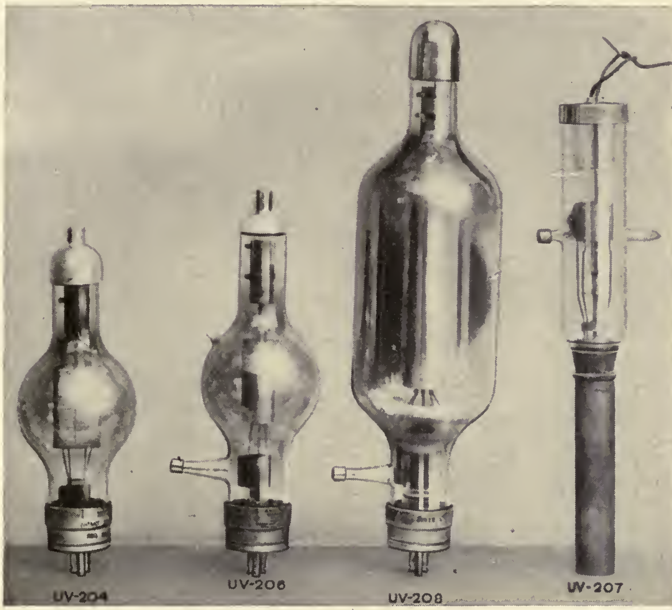


FIG. 125.—Power tubes for transmission. (Photo by Radio Corporation of America.)

in the rates of vibration of the two notes. Identically the same principle is used in the reception of continuous-wave telegraph signals. The local oscillating tube generating the continuous wave in the receiving circuit may be part of a separate circuit as in the case of heterodyne reception. Or the detector tube may be used for generating continuous waves as well as for acting as a detector, and then we have autodyne reception. The rate of oscillation of the receiving circuit may be varied, and the differ-

ence in rates of vibration between the incoming wave and the locally generated wave thus adjusted to any audible frequency so that the signal may be easily heard in the telephone receiver. The result produced is a succession of clear, whistling notes of long and short duration, corresponding to dots and dashes.

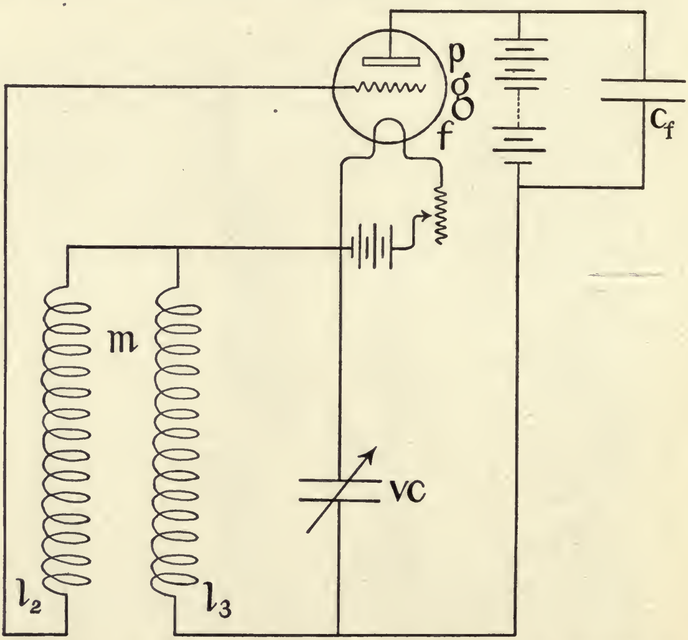


FIG. 126.—The heterodyne. Diagram showing the use of the vacuum tube as a generator of continuous waves: (*p*) plate in tube; (*g*) grid in tube; (*f*) filament in tube; (c_f) the fixed condenser; (l_2) grid inductance; (l_3) plate inductance; (*vc*) variable condenser.

The method employed to cause the vacuum valve to act as a generator of continuous waves may be understood by reference to Figure 126. The inductive coupling between the plate circuit and the grid circuit is shown at *m*. The inductive coils, between which this coupling is made, are shown at l_2 and l_3, and are commonly known as the grid inductance and the plate inductance respectively.

Small models of such a continuous wave generator are used as the source of the local continuous wave employed in connection with the receiving circuit to produce the "beat" effect required in receiving continuous wave signals. When so used this circuit is known as the heterodyne.

Practically the same system as shown in Figure 126, and explained above, may be used for producing the continuous wave sent out by transmitting stations. The vacuum tubes used in such stations are necessarily much larger than the small tube. Since, in transmitting, considerable energy must be supplied to the antenna circuit, it is necessary to withstand heavy voltage on the plate. The vacuum in the power tube must be extremely high; otherwise the effect of this high plate potential will be to produce a blue glow in the tube and impair its action. Comparatively large plate currents, due to this high plate potential, cause the transmitting tubes to become very hot. To prevent this excessive heating, the power tube is supplied with cooling devices such as heat radiating fins on the plate connection outside the tube. Devices are also now being employed which make use of circulating systems of water to carry away the excess heat.

In order to supply the high-voltage plate current, direct-current dynamos are installed as part of the transmitting equipment. Such a dynamo usually has two commutators so that the current for lighting the filaments of the power tube may be taken from the same dynamo that supplies the plate with the high-voltage current.

Because of the high vacuum required and the necessity for getting rid of the heat, the size of these tubes is limited. For large-power output several tubes are connected in parallel, so that it is possible to radiate considerable energy from the antenna of the continuous-wave transmitting station.

Since it would be quite impractical to break the dynamo current supplying the tubes, in order that dots and dashes could be sent from the antenna, some other means must be employed for modifying this antenna current to produce the desired signals.

Several turns of the antenna inductance are shorted by large relays. These relays are actuated by a current which can be controlled by the telegraph key or by some mechanical sending device. The effect of shorting a portion of the antenna inductance is to change the frequency of the transmission wave at intervals, corresponding to dots and dashes. The result at the receiving station will be a succession of notes at two different pitches which can readily be interpreted by the receiving operator into the dots and dashes of the telegraph code. If the tuning of the receiving station is sufficiently accurate, the only note heard will be the one caused by the frequency produced when the key at the sending station is closed. The wave which is sent out by the transmitting station when the key is not depressed is called the compensating wave. Very accurate tuning at the receiving end is necessary to tune out this wave. Later practice has been to ground this compensating wave through the water-cooling system of the tube so that it does not cause confusion at the receiving station.

It remains now to explain how speech and music may be sent out by radio. The principle of the radio telephone transmission is fundamentally the same as the principle of continuous-wave transmission, with the addition of some means of impressing on the continuous wave the sound or audio-frequency modulation. This modification is made, not in the frequency of the transmitting wave, but in its current strength or amplitude.

This impressing of the speech wave upon the continuous wave is known as voice modulation, and is shown in the diagram of Figure 127. The continuous wave in this case is called the carrier wave. Its frequency is very high, between five hundred thousand and one million double vibrations per second. This high frequency is necessary in order that the voice tones, with their varying frequencies of around five hundred to one thousand double vibrations per second, may be faithfully reproduced. Thus each wave of the sound will be outlined by the increasing and decreasing amplitudes of about one thousand radio waves.

Not this many radio vibrations are shown in Figure 127, but a sufficient number are indicated to show how the change of amplitude will impress on the high-frequency carrier wave the lower-frequency sound vibrations. A crude analogy may help to make this plain. If one drops a stone into a pond whose surface is covered with little wind-made waves, the wave emanating from the point of the splash will be a resultant jointly of the wind and the falling stone. The shore grasses, when the waves

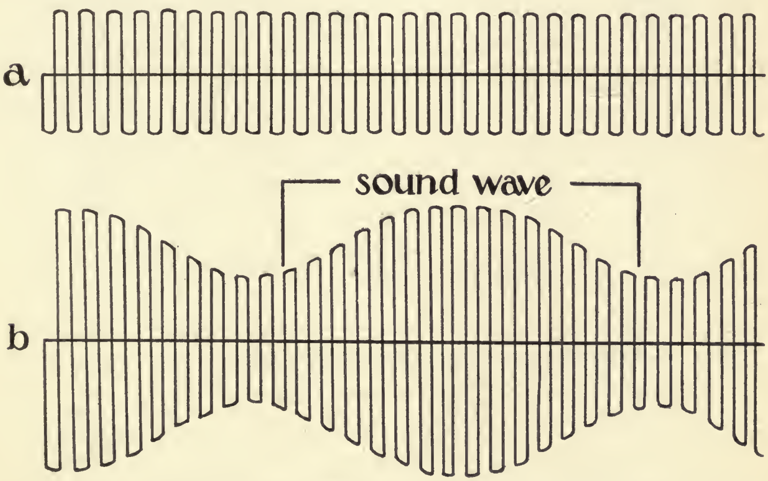


FIG. 127.—Diagram of voice modulation of a continuous wave

reach them, will not sway regularly as when only the wind waves hit them, but irregularly, moved by the waves that also bear the impress of the stone's disturbance. So the vibrations of the human voice are carried along with the high-frequency waves of the wireless telephone sender and register on the receiving apparatus.

This change in current strength of the carrier wave, without changing its frequency, may be accomplished by inserting a microphone in the antenna circuit of the transmitting station. This microphone is a telephone transmitter adapted for heavier

currents than the ordinary telephone transmitter. While this method of using the microphone in the antenna circuit is possible within very narrow limits of current strength, it is not practical. The reason for this impracticability is that large current strength in the antenna circuit is necessary for long-distance transmitting and broadcasting of lectures and musical programs.

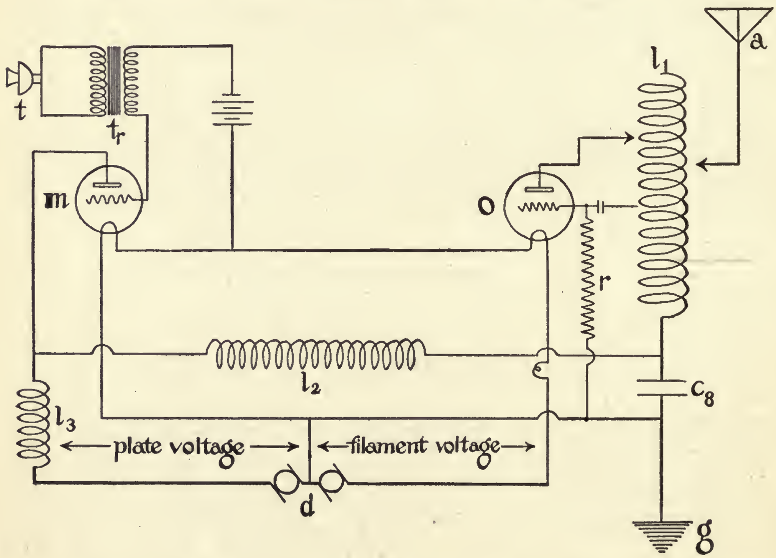


FIG. 128.—The radio telephone transmitter: (t) telephone transmitter; (t_r) telephone transformer; (m) modulation tube; (o) oscillating tube; (l_1, l_2, l_3) inductances; (c_8) fixed condenser; (a) antenna; (g) ground.

In order to produce this sound modulation in large radio telephone transmitting stations, recourse is again had to the vacuum tube. When used for this purpose, it is called a modulator. The connections for this use of the vacuum tube as a modulator in a radio telephone transmitting circuit are shown in Figure 128.

By a study of this diagram (Fig. 128) it will be noted that one tube (o) is connected into the circuit as a generator of continuous waves. The telephone transmitter or microphone (t) is con-

nected through a small transformer (*tr*) into the grid circuit of the modulator tube (*m*). The double commutator dynamo is shown at (*d*). This dynamo supplies both the filament current and the plate potential to both tubes. Inductances (l_2) and (l_3) are placed in the oscillating circuits. In actual operation several modulator tubes are connected in parallel to increase the strength of the speech-input current. There are also several generator tubes connected in parallel in order to increase the strength of the outgoing or carrier wave.

Very briefly the action may be explained as follows. When words are spoken into the transmitter, or microphone, a speech wave of audio frequency is impressed on the grid circuit of the modulator tube. This change in potential of the grid will produce corresponding changes in the plate current of the modulator. This oscillation of the plate current of the modulator causes this tube to build up or absorb energy from the antenna. This building up and reducing process corresponds to the vibrations of the sound taken in by the microphone. The carrier wave, then, is oscillating at regular radio frequency during the whole time the station is sending. At the same time the current strength of the antenna circuit, or the amplitude of the carrier wave, is vibrating at audio frequency. This audio-frequency vibration reproduces exactly all the sounds that strike the diaphragm of the microphone.

It will be recalled that a receiving circuit employing a simple crystal detector is used to pick up signals from discontinuous-wave sending stations. This result was explained as possible because the wave-trains were at audio frequency. Now, when such a receiving circuit is tuned to the frequency of the carrier wave from a radio telephone transmitting station, the frequency of the carrier wave is too fast to actuate the diaphragm of the telephone receiver. The result will be that no sound is produced by the carrier wave itself. The current intensity of the carrier wave is vibrating at audio frequency, corresponding to the sounds striking the diaphragm of the microphone at the sending station. This fluctuation in current strength will cause the diaphragm of

the telephone receiver to vibrate in exactly the same manner as the diaphragm of the microphone at the sending station. Thus the same receiving set used for receiving the dots and dashes from a discontinuous wave station is used for receiving the programs from the radio telephone broadcasting station (Fig. 129).

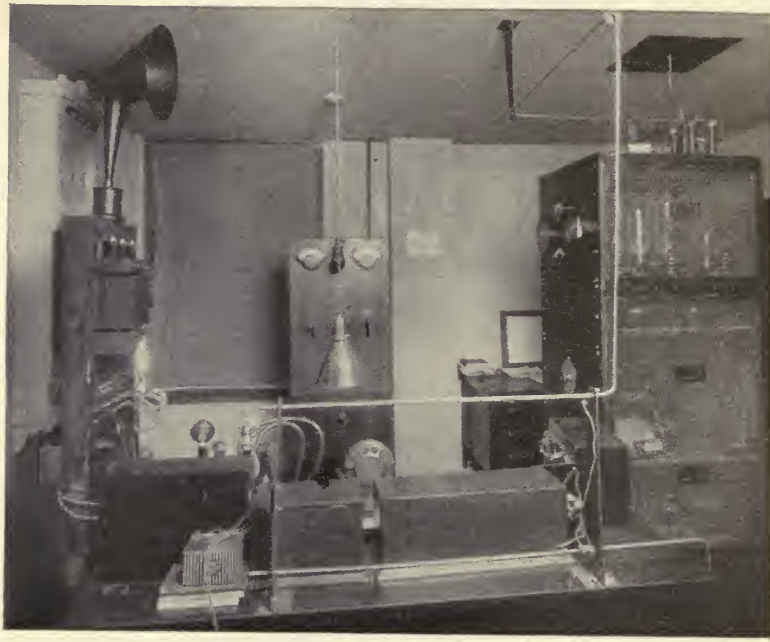


FIG. 129.—The operating room of a broadcasting station. (Photo by Sweeny Automotive and Electrical School, Kansas City, Mo.)

Much more elaborate systems of receiving equipment are commonly used for receiving educational lectures and musical programs from large broadcasting stations. The principle of their operation is identically the same as that of the simpler receiving sets previously described. In addition to the simple receiving circuit of these elaborate assemblies of equipment, there is usually an arrangement of vacuum-valve circuits whereby the incoming signal is very much amplified (Fig. 130). Loud-

speakers with megaphone horns are also employed so that a group may enjoy a musical program without each person being required to listen to the music from a small telephone receiver.

Government regulations require radio telephone broadcasting stations to employ wave-lengths or frequencies which are assigned to them on such a schedule that no large stations near each other will be sending on the same wave-length. Thus when two broadcasting stations operate in the same city, one

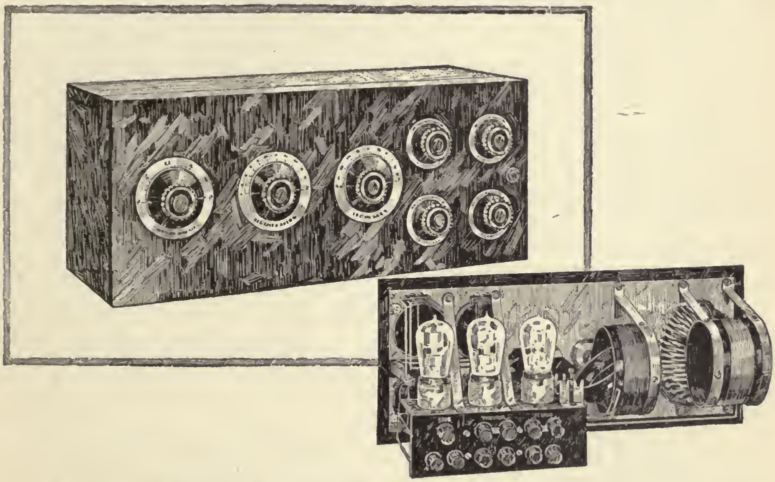


FIG. 130.—A modern receiving set. The tubes (amplifying and detector), condenser, coupler-coil, and tuner are shown mounted behind the panel.

station might have a wave-length of 411 meters while the other might be operating on a wave-length of 260 meters. This difference in wave-length, or frequency, enables the person receiving to choose one or the other, so that the musical programs or signals from one station will not be confused with those from the other station.

Development in radio transmission and receiving has been so rapid in the few years succeeding the war that any prediction as to its future use may easily be exaggerated. It seems quite within reason, however, to expect the radio methods of

communication to take over a very large part of the work now being handled by the commercial wire telephone and telegraph systems. Especially will this superseding of the wire systems by the radio systems occur where long-distance transmission is concerned. Radio communication is not subject to the serious limitations in expense of right-of-ways for pole lines and cables, the cost of maintaining large central stations, and the interference of communication because of the effects of such devastating elements as storms, floods, and fire.

CHAPTER XII

DEVICES FOR SEEING BETTER, FARTHER, AND LONGER.

Eyes are bold as lions, roving, running, leaping, here and there, far and near.—EMERSON.

When men observe a sequence of events in nature that is constant, the statement of such a constant sequence is called a law of nature. While we realize in general that nature conforms to law, yet we daily see repeated many phenomena or frequently make use of commonplace appliances without any appreciation of the laws that underlie their operation or even without a realization that there are laws governing such operation. One sees it grow light long before the sun is visible, and the strange fact does not challenge attention; or one plays a flute, turns on the electric lights, or uses the telephone, and yet is not even curious in regard to the laws that make such acts possible.

But the appreciation of some laws is so vital to our existence that they force themselves on our attention. We know them in practice, at least, even if we do not formulate them in words. Such is the law that light travels in straight lines. Very familiar experiences need only be recalled to make one realize the truth of this statement. When you see an object you want you reach straight for it, and you do not expect to see around corners unless a mirror is employed. The hunter sights along the straight arrow or gun barrel, and lets fly his missile at the animal he desires to kill. Nearly everyone has observed the straight beam of light revealed by the dust particles in its course in a partly darkened room. If you look at some object like a candle flame through holes punched in each of two cards held a foot apart, the flame and the holes must be in the same straight

line if the former is to be seen. Light then travels out from its source in all directions in straight lines.

It follows from this law that the intensity of illumination varies inversely as the square of the distance of the illuminated object from the source of light. Cut a piece of card 1 inch square and hold it 6 inches from a candle flame or small flash light in a dark room. Its shadow on a large white card or screen held at 12 inches from the light will be a square 2 inches on each side, or 4 square inches in area. The light, therefore, that covers 1 square inch at 6 inches from the source would cover 4 square inches at twice this distance. If the screen

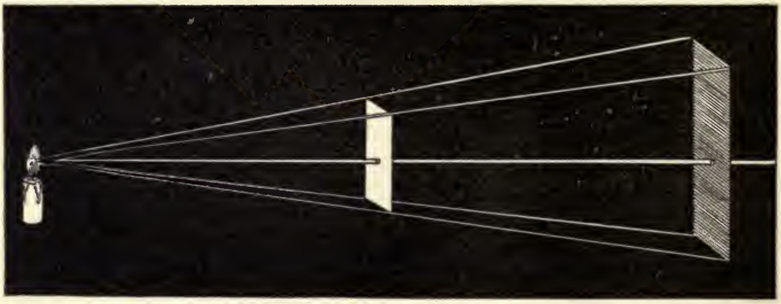


FIG. 131.—Diagram showing varying light intensities

be held 18 inches away, the shadow will be 3 inches on each side, or will cover 9 square inches. From the diagram (Fig. 131) it is evident that this law follows mathematically from the proposition that the area of the bases of similar pyramids vary as the squares of their altitudes, which is easily demonstrated by one familiar with geometry.

Practical application of this law is commonly made in measuring the relative intensity of illumination from different sources of light. This is usually expressed in terms of candle power. Thus we say that an electric light is a fifty-candle-power light. The standard is a carefully made candle of pure sperm, $\frac{7}{8}$ inch in diameter, that burns 120 grams an hour with

a flame of uniform intensity. The intensity of the light from an ordinary candle is quite variable.

Suppose we wish to measure the candle power of an electric light of unknown power. We may stand a nail or similar object upright on the table so its shadow will fall on a white paper or a ground-glass screen. Then place a lighted standard candle on the table so it will throw a shadow beside that made by the electric light. Move the candle nearer to or farther from the nail until the two shadows are equally dark. The comparison is easily made when the shadows are side by side on the paper or screen. Suppose the candle is then 1 foot from the nail and the electric light is 10 feet away. The relative intensity of the two lights is as the square of these distances. The electric light is, therefore, one of 100 candle power. (An ordinary candle may be used to show the principle of the experiment, but the result will not be exact.)

Another interesting application of this principle that light travels in straight lines is seen in the pinhole camera. This may be made as follows. Secure a small light-tight wooden or pasteboard box—a starch box or chalk box. In the center of one end bore a tiny hole, like a pinhole. Cut out the other end of the box, and over the opening fasten a piece of white tissue paper or, better still, tracing paper or tracing cloth. Set this box on the sill of an open window, pinhole out. Throw a dark cloth or your coat over your head and also over the end of the box covered with the tracing paper. Hold the cloth or coat tightly around the box so that no light gets to your eyes. Look, now, on the tracing paper and you will see an inverted image of the landscape in front of the camera. Every point in that landscape is sending a tiny beam of light in a straight line through the pinhole to the paper to make a part of the image (Fig. 132). If a second hole were punched near the first, another image would be formed that would overlap and blur the first. Then if the hole made in the end of the box is large instead of small like a pin prick the overlapping images are all indistinct, and the

tracing paper is illuminated but shows no distinct picture of objects.

If, in place of the tracing paper, a photographic plate is set so as to cover the opening opposite the pinhole with its sensitive or film side which is the dull side toward the hole, you can take a picture with this camera. You must take the plate out of the box or package in which you buy it, in a room that is entirely dark except for the photographer's lamp used to give you light (see "darkroom" below), and fasten it in place. Cover that end of the box and the plate with the dark cloth and keep your finger over the pinhole until the camera is in position on the

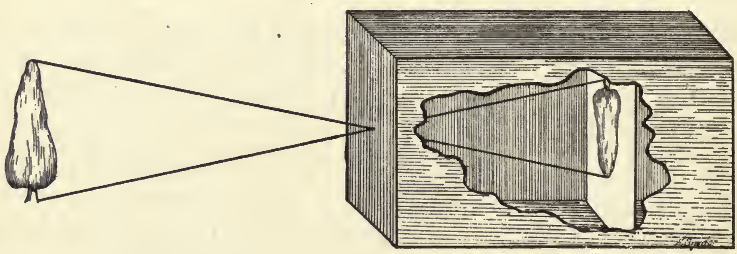


FIG. 132.—The pinhole camera

window sill. Then uncover the hole for three or four minutes if the sun is shining and it is the middle of the day, much longer if the day is cloudy. The plate must then be developed to bring out the picture (see below).

A modification of the pinhole camera is used in sketching objects or in mapping landscapes. The device is known as a camera obscura. Take a good-sized wooden box that is light-tight and large enough to receive your head and shoulders. Remove the top of it. Paint or stain the inside dull black. In the middle of one side, 6 inches from one end, bore a small hole with a drill. At the middle of the end adjacent to the hole set a 6-inch post at right angles to the end. Mount on this a plane mirror facing the drill hole and inclined 45° to the post

so that the light entering the hole will be reflected by the mirror down on to the other end which is to be the base of the instrument. Tack an ample, dark curtain on to the open top of the box, fastening it at the end near the drillhole and to the adjacent sides so that when head and shoulders are introduced into the box it will cover them and exclude the light. Set the instrument base down on a table out of doors or on legs fastened to the base. Lay a piece of white paper on the base inside the box. Light now coming through the drillhole is reflected by the mirror on to the paper, and forms there an image of the object to be sketched or of the landscape to be mapped. With pencil in hand and your head and shoulders under the curtain you can trace the outline of the picture desired. The image will be much brighter if a long-focus camera lens is used in place of the drillhole because it will admit much more light (Fig. 133).

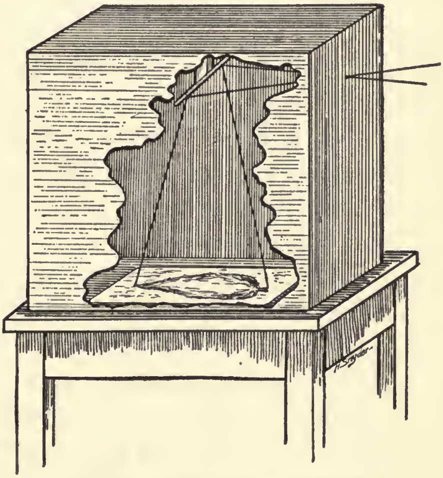


FIG. 133.—The camera obscura

The ray of light will be bent out of the straight course in which it usually travels (1) when it strikes a reflecting surface like that of a mirror; (2) when it enters or leaves a substance more or less optically dense than the one in which it is traveling, as when it enters the water from the air or passes through a glass lens. We must undertake to comprehend some simple laws of reflection and refraction in order to understand such instruments as the magnifying glass, telescope, camera, and other contrivances that man has invented in order to see better, and farther, and longer.

Some of the principles that underlie reflection are matters of familiar experience. You know that when one looks at himself in a mirror his right hand seems to be on the left side of his image. If his hair is parted on the left, the image wears its parted on the right. If he winks his right eye, the image winks its left. A person and his mirror image face each other in the same relative position as two persons facing each other. A movement of the right hand toward the right appears in the image as a movement of its left hand toward the left. We have grown so accustomed to performing certain actions before the mirror, such as combing the hair or tying a tie, that we are not confused by the reversal. But undertake some unusual task, looking at your action in the mirror, and it is difficult. Thus, as you sit at the table, stand a book on edge on the table in front of you. Behind it on the table lay a piece of writing paper. Stand a mirror on the table beyond the paper. Now place your hand on the paper ready to write and adjust the mirror so you can see your hand and what you write, in the mirror, but cannot see them by direct vision because the book is in the way. Then write your name so you can read it in the mirror.

It is a more or less familiar fact that the image as seen in a plane mirror seems as far back of the mirror as the object is in front of it. We all know, too, how curved mirrors distort images. As a child you probably amused yourself by looking at your face in the back of a shiny spoon and then in its bowl, seeing your distorted image upright at first and then upside down. All these phenomena pertaining to mirrors are easily understood when one fixes in mind a very simple law, namely, that the ray of light which strikes a reflecting surface is sent off from it at the same angle at which it strikes, or, in other words, the angle of reflection equals the angle of incidence. This will be appreciated by a simple experiment. Stand a mirror on a table so that the surface of the mirror is at right angles to the surface of the table. On the table in front of the mirror lay a sheet of paper, one edge against the edge of the

mirror. Set a pin in the paper some distance in front of the mirror and considerably to one side of its center. With the eye at the level of the table and near the opposite edge of the paper from the pin, lay a ruler upon the paper, its edge in line with the eye and the image of the pin seen in the mirror. Extend this line to the mirror. From the point where it meets the mirror draw a line to the pin. The angles these two lines make with the edge of the paper that coincides with the face of the mirror will be equal, and may be roughly proved so by cutting one out and laying it on the other.

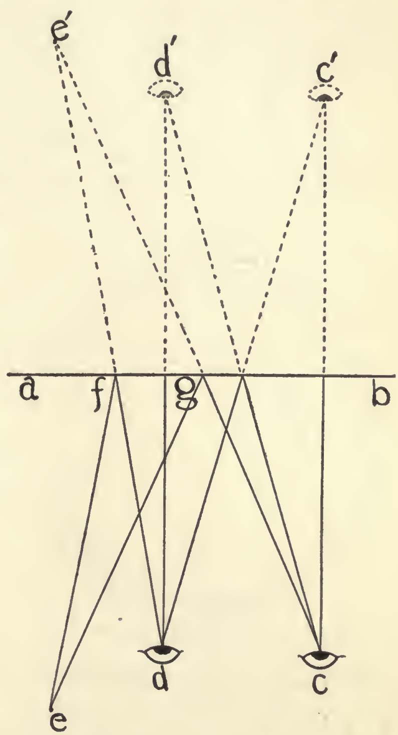


FIG. 134.—Reflection in a plane mirror. The image seems as far behind the mirror as the object is in front of it.

A similar law is practically familiar to every child who throws a ball against a wall or the sidewalk and catches it as it rebounds. It is still more evident if one person throws the ball against wall or ground and another person, at some distance, tries to strike it, as in handball or tennis. The angle at which the ball hits the wall or ground is the same as the angle at which it rebounds, due allowance being made for inequalities in the surface and the twisting motion of the ball. The billiard player depends constantly on this principle as the balls rebound from the cushions on the edge of the table. Suppose *ab* (Fig. 134) represents the surface of a mirror, *c* and *d* the eyes of a person looking in the mirror, and *e* the tip of his left ear. Beams of light from

e strike the mirror at f and g, and are reflected into the eyes of the observer. He sees the image of e at e'. Similarly, he sees c and d at c' and d' respectively. But these imaged eyes appear to face him from back of the mirror. The ear e' of the image is at the right of its eyes, while the ear of the observer e is at the left of his eyes. The eye d' is the right eye of the image, while the corresponding eye, d, of the observer is his left eye.

Note that e' appears as far to the rear of the mirror as e is in front of it, because we judge the distance of an object by the angle between the rays of light entering the two eyes from it. This angle is evidently the same after reflection from the mirror as when the rays start from e. The eyeballs are turned in their sockets by delicate muscles that are richly supplied with sensitive nerves (Fig. 135). So we are able to sense just how much the axes of the two eyeballs converge when we fix our eyes on an object. The axes evidently converge strongly when a very near object is examined, e.g., the tip of one's own nose, less strongly as the object is more and more distant. That the two eyes are used in such estimation of the distance of an object is made apparent by a simple experiment. Tie a finger ring to one end of a piece of fine wire or thread. Fasten the other end of the wire to some object, such as an electrolier or a door frame, so the ring hangs freely about breast high. Step away from the ring 2 or 3 yards and face its edge. Take a pencil in your hand, close one eye, then walk up to the ring and pass the pencil through it from right to left, with the eye still closed.

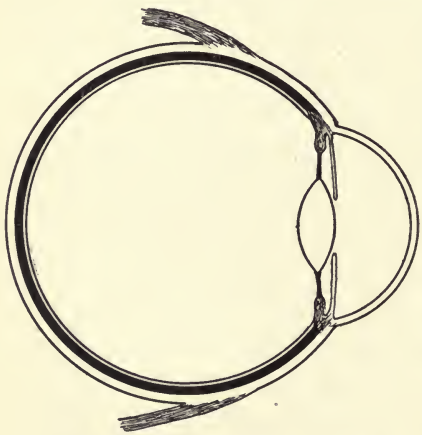


FIG. 135.—Section of the eyeball

The knack of judging distances is one that we acquire very early as we correlate repeatedly the play of these muscles that move the eyeball with our experience in reaching for objects or in walking to them. Other factors enter into our judgment of distance, such as the operation of the muscles that control the focus of the lens of the eye, the haziness of the image when objects are very distant; but they may be neglected in this discussion of the apparent position of the mirror image.

You may have been amused and possibly confused by going into a mirror maze—a room whose walls are set with mirrors projecting at various angles. You see yourself in many places simultaneously, and when you try to find the door to go out it is difficult to tell which of the many doors you see is the real one. The production of such multiple images may be illustrated with a simple experiment. Stand two long mirrors on edge, one end of each near the margin of a table, so that they are parallel and face each other a foot or so apart. Between their ends that are distant from the edge of the table, set some object, say a spool. With your eye between the other ends of the mirrors see how many images of the spool you see. Change the position of the mirrors so they stand at an angle to each other instead of lying parallel. How does this affect the number of images visible? One of the most fascinating illustrations of multiple images is found in the child's toy—the kaleidoscope. Directions for making this are found on page 83 of the *Field and Laboratory Guide in Physical Nature-Study*.

Suppose *ab* (Fig. 136) represents the surface of a cylindrical mirror whose center of curvature is shown at *c*. The eye of an observer is shown at *f*. The points *d* and *e* are the tips of an arrow, the image of which is seen in the mirror by the observer. If *ab* were a plane mirror, the image would appear as large as the object and would be seen as far behind the mirror as the arrow is in front of it. But since the light is now reflected from a convex surface, the rays from *d* to the eye will be rendered more divergent than they would be if reflected from a plane

surface. When, therefore, they are produced back of the mirror to meet at the point d', they meet nearer the mirror than is d.

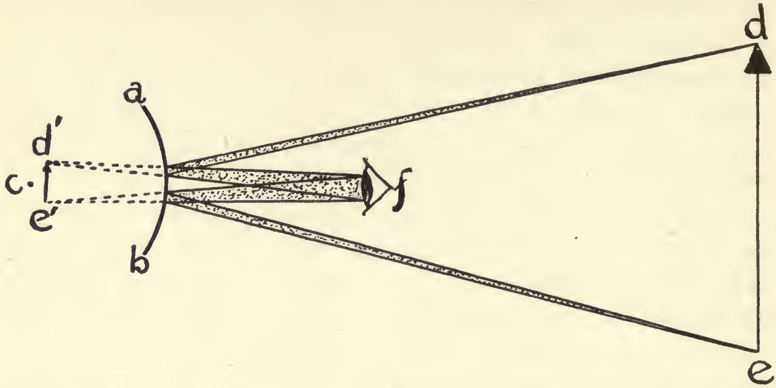


FIG. 136.—Reflection from a convex mirror. The image of the large arrow at the right is seen by the eye at the left and is relatively small.

Similarly, e' is nearer the mirror than e, and d' and e' are closer together. The image of the arrow is, therefore, smaller than the arrow itself. An observer, seeing himself in such a cylindrical

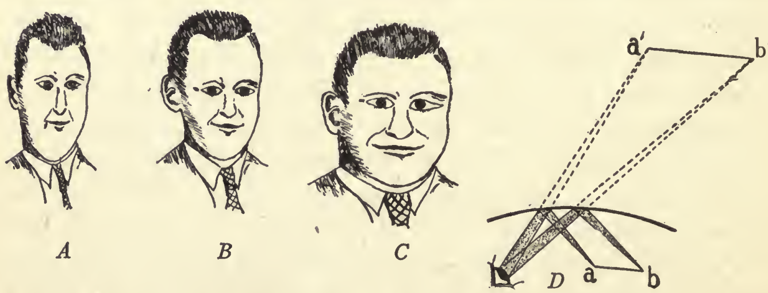


FIG. 137.—Images of a man: *A*, as seen in a convex cylindrical mirror; *B*, as seen in a plane mirror; *C*, as seen in a concave cylindrical mirror. *D*, Diagram showing why the concave mirror broadens the face.

mirror when its long axis is parallel to his height, will see himself narrowed from side to side while his vertical size will be unchanged.

If now one looks at himself in the concave surface of a cylindrical mirror when its long axis is parallel to his height,

evidently just the reverse will be true, and his image will appear broader than he is (Fig. 137).

Consider next the case of a concave mirror whose surface is the segment of a sphere. If one looks for the image of a candle flame in such a mirror, there are three possible positions which the candle flame may occupy: it may be (1) at the focus of the mirror, (2) outside the focus, (3) within the focus. If such a source of light should be at the center of curvature of the mirror, all the rays will be reflected back to the same point, since they move out along the radii of the curved surface, which radii are perpendicular to that surface. If parallel rays of light strike such a mirror, they will all meet after reflection in a point known as the focus, and this point must be halfway between the mirror and its center of curvature. Light emanating from the focal point will be reflected evidently as parallel rays, while rays emanating from a source nearer the mirror than the focus will be reflected as divergent rays.

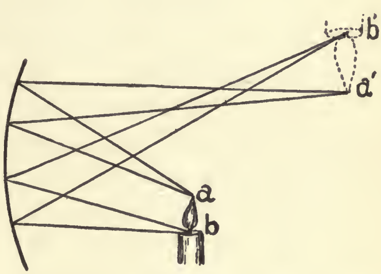


FIG. 138.—An object and its image formed by a concave spherical mirror.

Rays coming from a source farther from the mirror surface than the focus will meet at a point. These two points, the one from which the rays emanate, the other the one to which they converge, are known as conjugate foci.

If an object like a candle flame is at *ab* (Fig. 138), the mirror will form an inverted image of it at *a′b′*, which image may readily be seen on the screen at this position. If, however, the candle flame were at *a′b′* (turn the figure upside down), the image would evidently be at *ab*.

If the object is nearer the mirror than is the focus, no actual image will be formed; but if the eye catches reflections in the mirror from such an object, the object will appear magnified.

Suppose, for instance, points *a* and *b* (Fig. 137*D*) represent the opposite ends of an arrow seen reflected in a concave mirror, these points being slightly nearer the mirror than its focus. Follow two rays of light, the outer or the marginal rays of a pencil of light, from point *a* to the mirror. When these are reflected into the pupil they are less divergent than when they left *a*. They will seem, therefore, to come from a point back of the mirror and farther from the mirror than *a* is in front of it. Similarly, *b* will appear at b', and the arrow will seem larger than it is. So a dentist uses a small concave spherical mirror to see his work on a tooth, and thereby magnifies the cavity he is cleaning and filling.

An image is formed by a lens because the light entering and leaving it is bent from its straight course or is refracted. Such refraction always occurs when rays of light go into or out of an optically more or less dense medium than the one in which they were traveling, and the refraction occurs at the line of demarcation of the two media. Thus light entering water from air is refracted as it enters the water. Optical density and ordinary physical density must not be confused. Thus carbon disulphide is a liquid and not physically as dense as glass; yet optically it is more dense than most glass, that is, it bends the ray of light entering it more than does glass, or to put it in another way, it has a higher refractive index than glass.

One may perform a simple experiment that will help clarify this notion of refraction. Put a penny in a bowl that sits on the table. Stand where you can just see the penny over the edge of the bowl, and then step back until you just cannot see it. Have some other person pour water into the bowl carefully so as not to move the penny. The far side of the penny begins to appear, and as the level of the water rises you see more and more of it until it is all in sight. Evidently the rays of light, coming from the penny over the edge of the bowl, go above your eyes before the water is added, and after that are bent down so that they enter your eyes. (See Fig. 139.) If one draws a

line perpendicular to the surface of the water at the point at which the ray of light leaves the water and enters the air, point *b*, Figure 140, one may state the direction of the refraction as away from the perpendicular when the ray passes from an optically dense medium to a less dense one (water to air), and toward the perpendicular when the light moves in the opposite direction, as would be the case if eye and coin interchanged positions in this experiment. In spearing a fish, from behind it, one must aim the spear at its tail in order to hit its body, or if it is lying in deep water the spear must be thrust at a point back of the fish in order to hit it at all.

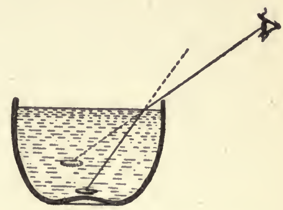


FIG. 139.—Diagram showing refraction of light from an object in water.

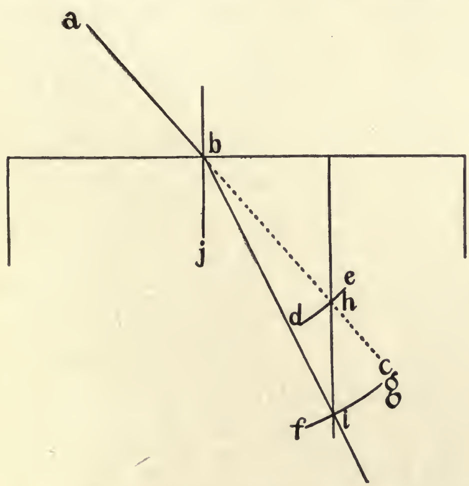


FIG. 140.—Diagram showing method of finding the path of a ray of light entering glass.

The amount of the refraction depends on the relative density of the two media. Air is taken as the standard, and when we say that a given sort of glass has an optical density of 1.5, we mean that it is half again as dense as air, or that light travels through it only two-thirds as rapidly as through air. Practically we apply this in tracing the course of the ray as follows: Suppose *ab* (Fig. 140) is a ray of light which at *b* enters the plane surface of a piece of glass with a refractive index of 1.5. With point *b* as a center and a radius of 1 (in the diagram the radius is 1 inch), strike

off the arc *de*. With *b* as a center and a radius of 1.5, strike off the arc *fg*. Continue the line *ab* toward *c*, and from the point *h* where this line intersects the arc *de* erect a perpendicular to the surface of the glass and extend it until it intersects the arc *fg* at *i*. Through *b* and *i* draw a line, and this will be the course of the ray after refraction. It is evident that the ray *ab* is refracted at *b* toward the perpendicular *bj* erected at *b*.

Now suppose that the ray of light is coming out of a block of glass with refractive index of 1.5 (Fig. 141). The ray *ab* strikes the surface of the glass at *b* and enters the air. If it were not refracted, it would continue toward *c*. This ray, on entering the air from the glass, will be refracted away from the perpendicular. (Recall the experiment with the penny and bowl.) To determine its course, proceed thus: With *b* as a center and a radius of 1, strike off an arc *de*, and similarly a second arc *fg*, with radius of 1.5. From *h*, the point where the extended ray intersects the arc *fg*, drop a perpendicular to the extended face of the glass. This cuts the arc *de* at *i*. Draw the line *bi*, and this will be the course of the ray. One can readily judge whether the perpendicular is to be dropped from the intersection of the extended ray with the arc whose radius is 1, or the arc whose radius is 1.5, by thinking whether the refraction is to be toward or away from the perpendicular; and the experiment with bowl and penny will recall this. If the refractive index of the glass were

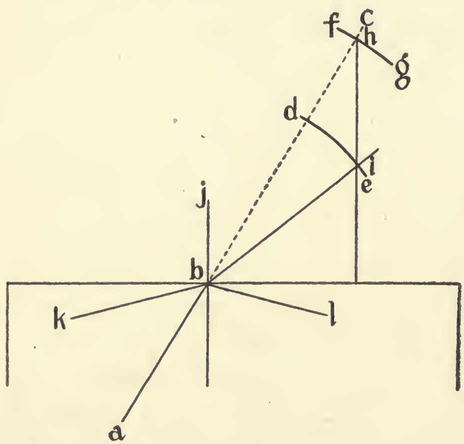


FIG. 141.—Diagram to show method of finding the path of a ray of light leaving glass.

1.25 instead of 1.5, then the radius of the second arc would be taken as 1.25 inches.

If the ray of light were to strike the glass surface at a small angle, as the ray *kb*, it would be refracted back into the glass if it could get out. At such an angle it is, therefore, totally reflected at *b* to *l*.

Some simple experiments with any convex lens like a magnifying glass or a reading glass will help make clear some things that it is necessary to understand in order to comprehend the working of cameras, microscopes, telescopes, or other instruments using lenses. If you hold such a lens so that the rays of sunlight will strike it squarely, the light is brought to a single point on any surface such as a sheet of paper held at the proper distance from the lens (Fig. 142). The sun is so far away that the rays of light entering the lens are practically parallel. The point at which these rays meet is known as the focus of the lens, and the distance from that point to the lens is the focal length of the lens. To be

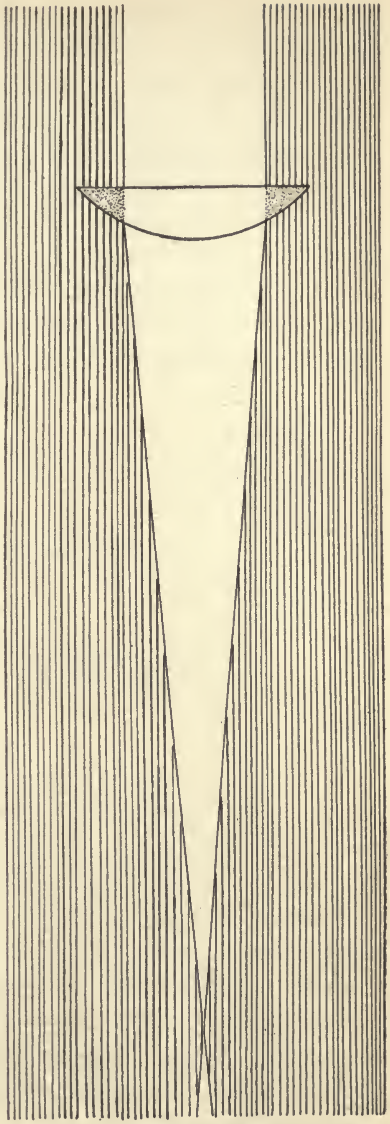


FIG. 142.—The beam of light brought to a focus by a plano-convex lens, or burning glass.

exact, the measurement should be made from the focus to the optical center of the lens, but the rough measurement to the face of the lens is adequate for our purpose.

Set a lighted candle on the table. Hold the lens in your left hand a foot from the candle flame. Hold a sheet of paper in your right hand on the opposite side of the lens from the candle flame, and move this sheet closer to, or farther from, the lens until a clear image of the candle flame is seen on the paper. Note the size of the image. Move the lens to about 6 inches from the flame. Note now that the image is no longer distinct. To obtain a distinct image the screen must be moved farther away

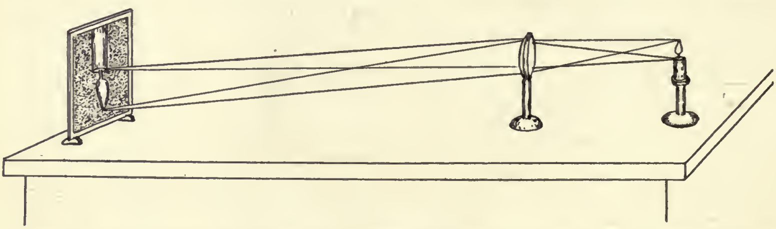


FIG. 143.—Candle and screen are at the conjugate foci of the lens. Two pencils of light are shown, focusing to form two points of the image; similar pencils emanate from other points of the candle, and are brought to a focus to form corresponding points of the image.

from the lens, and the image will be much larger than before. On the other hand, if the lens is moved so that it is 2 feet from the candle flame, the screen must be brought nearer the lens, and the image will be smaller than in either previous position of the lens. It is evident that the light emanating from the candle flame is brought to a focus at the place where the image is formed. If the candle and the screen were interchanged in position, there would still be a sharp image of the flame upon the screen. These two points are known as conjugate foci, and the nearer one of these is to the lens, the farther away the other must be (Fig. 143).

Lenses may be either convex or concave, the former bringing parallel rays of light to a focus, the latter making such rays

diverge. The convex lens may have both faces convex, one plane and one convex, or one less concave than the other is convex. Similarly, concave lenses may be double concave, plano-concave, and the concave meniscus (see Fig. 144).

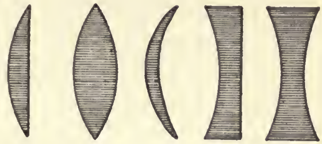


FIG. 144.—Lenses of several shapes

If the principles of operation of a convex lens, given above, have been grasped, it will be easy to understand the operation of many optical instruments. Let us see why it is that a magnifying glass magnifies. The object to be examined must be

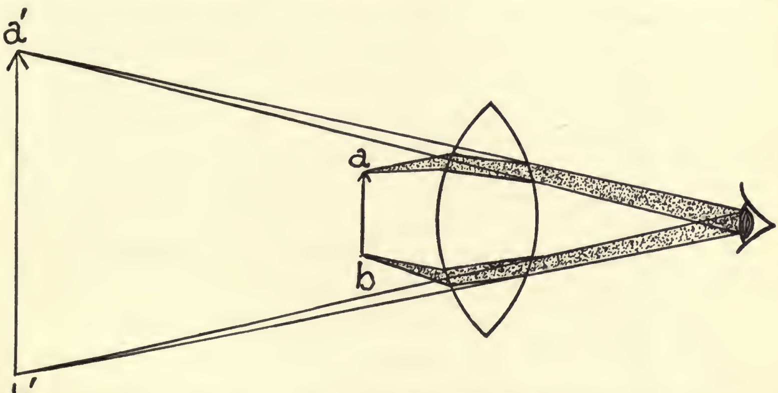


FIG. 145.—Diagram showing how a magnifying glass magnifies

placed nearer to the lens than is its focal point. Rays emanating from a point in such an object, as from *a* in the diagram (Fig. 145), will be less divergent after passing through the lens than they were on entering the lens. When such rays enter the eyes they will be referred back to a point at their intersection, and this point *a′* is much farther from the lens than is the point from which they really came. Similarly, point *b* of the little arrow will be referred back to *b′*, and intermediate points of the objects to a position between *a′* and *b′*. One therefore sees the object enlarged. Under these conditions no actual image is formed, but the image seen is spoken of as a virtual image.

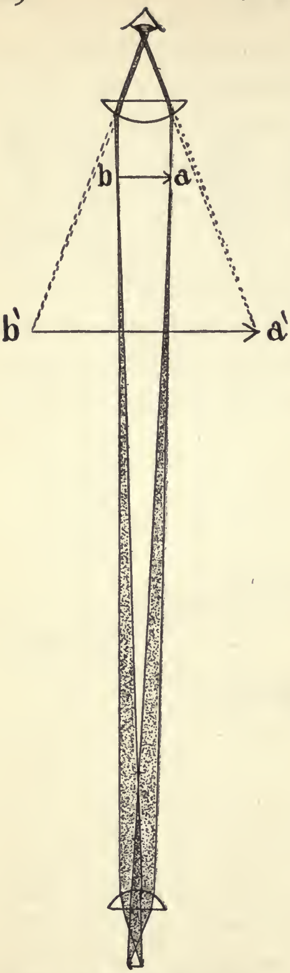


FIG. 146.—Diagram of a compound microscope. An object represented by the small arrow at the bottom of the figure is so placed that rays of light leaving it are brought to a focus at *ab* after passing through the object lens or objective, there forming an inverted image. The rays pass on through the eye lens or eyepiece, diverging less as they pass, and the eye seems to see the magnified virtual image at *a′b′*.

You may make lenses for yourself in either one of two ways that will serve for the time being. First, good-sized lenses may be made from two watch crystals of the same size. Smear their edges with vaseline. Immerse them in water, and bring them edge to edge so that the space between them is filled with water. Be careful not to include air bubbles. Hold the two firmly together between the thumb and fingers of the left hand, lift them out of the water with their contained water, wipe the edges dry and bind them together with a strip of surgeon's adhesive tape as you would *passe-partout* a picture. The tape may be purchased at any drugstore, and the 1-inch width is best. If the water runs out from between the watch crystals and air leaks in during this process, try it again. It will do no harm if a small bubble of air gets in, but it should not occupy more than one-fifth or one-sixth of the interior. Such a lens will work well as a magnifying glass.

A second method of making a small lens is as follows: Take a circular cover glass such as is used in the preparation of microscopic mounts. Hold it in a pair of spring forceps such as the bacteriologist uses, and drop on to it some liquid glass or thick Canada balsam. Heap up as much as it will hold without running off, then

turn the cover glass over so the liquid glass or balsam will hang from the under side, the lower surface of it in the shape of the segment of a sphere. Allow this to stand until it hardens. A lens of this sort may be used in making a microscope or for the eyepiece of a telescope. The large-sized lenses made from watch crystals are serviceable also as objectives for telescopes or magic lanterns or as condensers for magic lanterns. Directions for making a microscope, telescope, and magic lantern are given in the *Field and Laboratory Guide in Physical Nature-Study*. The principle of operation may be explained here.

The microscope consists of two lenses mounted at the opposite ends of a tube which is about 1 inch in diameter and several inches long. One of these lenses, the one through which you look, is the eyepiece; the other, which is brought close to the object to be examined, is the objective. The object to be examined is brought near enough to the front of the objective so that an image is formed up in the tube of the instrument just below the eyepiece. This image is then examined by the eyepiece, which serves as a magnifying glass (Fig. 146). Recalling our experiment with the convex lens and the candle flame, it will be remembered that when the flame was near the lens the image was relatively far from the lens and larger than the object. The image formed below the eyepiece is therefore enlarged, and when the eyepiece magnifies it still more, one sees the object hundreds or even thousands of times larger than it really is. There are some accessory parts to the microscope (Fig. 147), which make it more convenient, but the lenses held by the tube are the essential things. There is usually a heavy base on which the instrument stands, and a pillar that carries the tube on a movable arm. This pillar also bears the stage on which the object to be examined is placed, and a mirror to throw light on the object to be examined. In addition there is a coarse adjustment that moves the tube rapidly up and down by means of rack and pinion, and a fine adjustment that moves it very delicately. The objectives, especially of a good microscope, are built of several lens

elements so as to free the image from distortion and fringes of color.

The telescope is very much like the microscope, except that the object to be examined is a long way off, but the objective

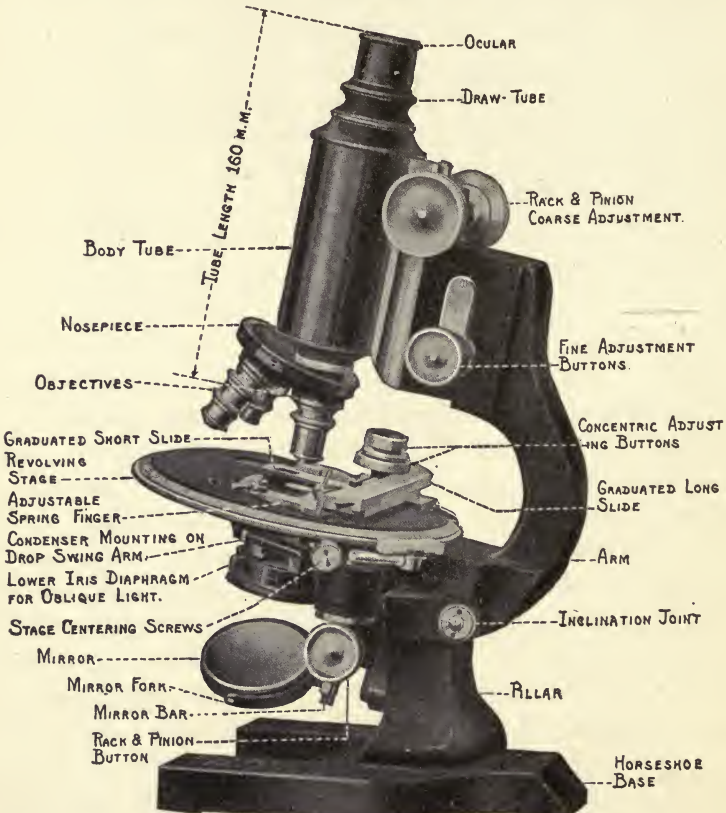


FIG. 147.—A compound microscope. (Courtesy of the Spencer Lens Co.)

still forms an image of the object which is examined by the eye-piece that magnifies it (Fig. 148). So that this image may be as large as possible, the tube of the telescope is often very long (see Fig. 149). In both telescope and microscope the tube is not essential, but it is convenient to shut out the light from

surrounding objects so that the image is seen on a dark background. If you will take two convex lenses, one in each hand, and hold one at arm's length as an objective, the other near your eye as an eyepiece, and hold them both in line with some distant object, you can, by varying the distance between them, get the effect of the telescope without a tube.

In the magic lantern or stereopticon, the light from some source of illumination, as an electric lamp, is made to converge by convex lenses on to the transparent glass slide that bears the picture to be shown. The picture is printed on the gelatine film on the slide and must, of course, be transparent. The light from the condenser goes through the slide to the objective. The slide is at one of the conjugate foci of this convex lens which we call the objective, whose other focus is at the screen. Since the slide is near the objective, the screen will be far away and the image formed will be much larger than the picture on the slide. (See Fig. 150.)

In the more expensive types of lenses in the camera, microscope, and telescope, the lens is made of several elements or separate lenses that are mounted together to make the so-called lens. This is necessary because of two defects in any single lens: (1) spherical aberration, (2) chromatic aberration.

If you will hold in your hand any large convex lens like a large reading-glass and look through it toward the window, then move it nearer to or farther from your eye until you see the image of the window, you will note that the

FIG. 148.—Diagram of telescope. The nearly parallel rays of light from the distant object are focused so as to form an image near the eyepiece, which acts as a magnifier to enlarge it. In opera glasses an extra lens is added to make the image appear right side up.

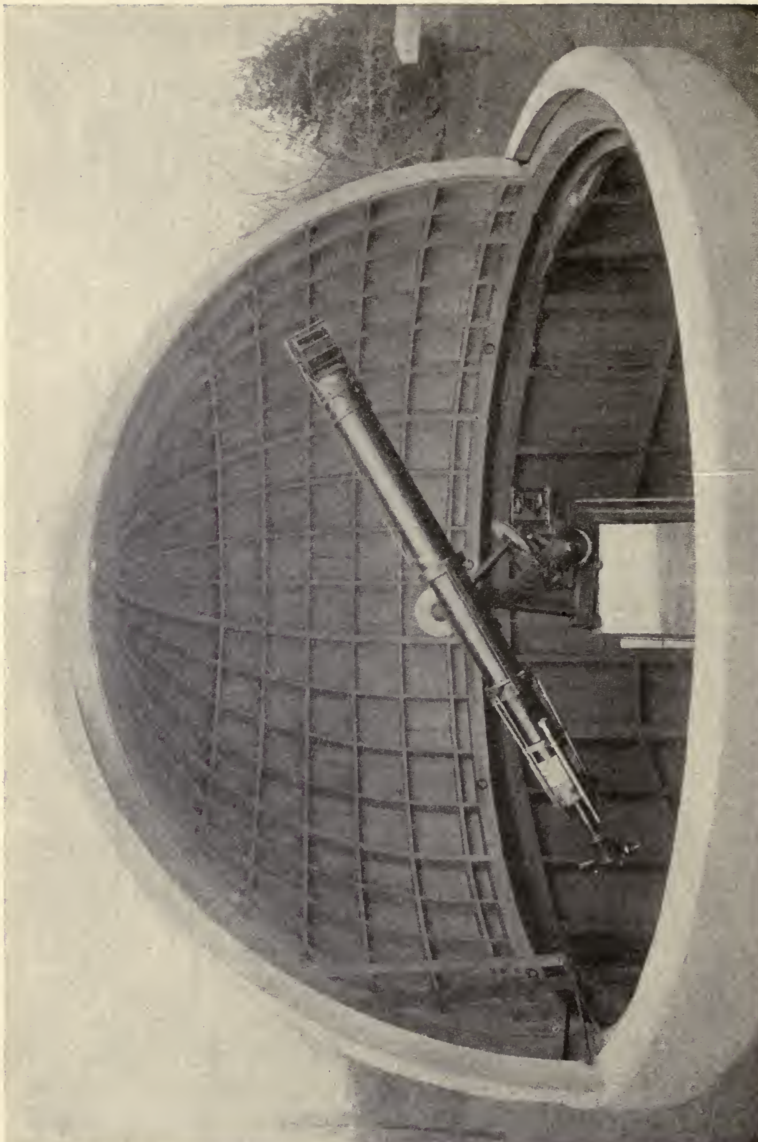


FIG. 149.—A telescope and its mount

vertical lines of the window frame that bound the panes of glass appear not as perfectly straight lines but as more or less curved lines. This is due to the fact that the rays passing through the margin of such a lens and those passing through its center do not come to a focus at exactly the same spot. If you will cut a small circular opening one-half inch in diameter in a piece of cardboard or thick paper and lay it on the lens so that all the lens is covered except its central area and try the foregoing experiment again, you will find that the image which you see is largely freed from this spherical aberration. So you will find a diaphragm inserted in the lens of many optical instruments to accomplish this correction. The iris of the eye is in part for this purpose. When

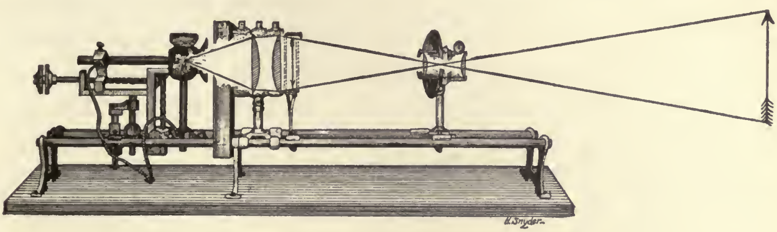


FIG. 150.—Diagram of a stereopticon

one is out at night, the pupil is very large to admit as much light as possible, as you will readily see if you look at your eye in a mirror immediately on coming in from the dark. Because the pupil is so large, the image is not very distinct, and we often mistake commonplace objects for terrifying things.

The curved surfaces of a convex lens are segments of spheres. If the surfaces could be paraboloid surfaces instead of spherical, this defect would not occur. But it is very difficult to grind lenses with paraboloid surfaces and very easy to grind them with spherical surfaces. A piece of glass to be made into the form of a lens is cemented to the end of a stiff rod; the other end of the rod is pivoted at a point above a horizontal rotary grindstone so that the glass presses on the surface of the grindstone. It is evident that the rod is the radius of a sphere, and

that, as the glass is ground down, the surface formed will be a spherical surface. The amount of curvature of the surface will depend upon the length of the rod used.

If you look through a glass prism at some object such as the window sill, you will demonstrate first that the prism must be so placed as to allow the ray of light coming from the window sill to enter your eye after its refraction. If you will think how the ray of light is refracted (see Fig. 151) on entering and leaving an optically denser medium than the air, you will have no difficulty in placing it in approximately the correct position at your first trial. You will note, secondly, that the window sill seems surrounded with a halo of color. A convex lens may be thought of as a series of prisms, and you will observe as you look through your large convex lens that the image of an object seen does have a fringe of color about it. This defect of the lens is known as chromatic aberration.

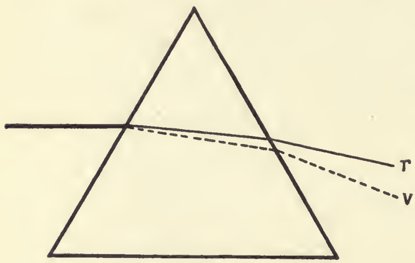


FIG. 151.—Diagram showing refraction of light by a prism. The beam entering the prism is not only refracted but also dispersed into its component colors, only the extremes of which are shown, the red (*r*) and the violet (*v*).

This defect is remedied in large measure by making the lens of several elements. This power of glass, or similar refractive media, to spread the component color rays of white light so that they form a color band as in the rainbow is known as its dispersive power. Fortunately, the refractive power and the dispersive power of lenses are largely independent of each other, so that one kind of glass may have high refractive power but low dispersive power, while another sort has low refractive power but high dispersive power.

Suppose then we were to put behind a plano-convex lens (see Fig. 152) of high refractive but low dispersive power a

plano-concave lens of low refractive but high dispersive power, an image may still be formed that is free from the color fringe because the second lens will not overcome the refraction of the first lens completely, while it will undo the dispersive effect of the first lens. Now to grind and combine two or more lenses so as to correct their defects is a laborious process that requires great skill, hence the superior photograph, microscope, or telescope lens must be costly.

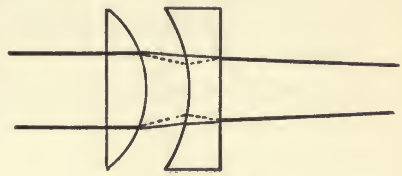


Fig. 152.—Correction of chromatic aberration of a convex lens by a concave lens.

In the human eye there is such a combination of lenses. The aqueous humor in the front of the eye is in the shape of a convex meniscus; then comes the double convex crystalline lens; then the vitreous humor making a plano-concave lens, plane on its posterior side because the retina is imbedded in it so that no refraction occurs as the light passes from it to the retina (Fig. 135, p. 288).

According to the still generally accepted theory, light is due to waves in the ether or in other substances through which it is passing. The wave form advances, but each molecule moves in a tiny orbit somewhat as do the particles of water when a

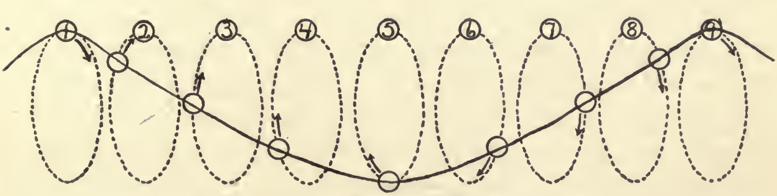


Fig. 153.—Diagram showing wave motion

water-wave forms. Thus in Figure 153 molecule 1 is struck by an impulse that makes it vibrate or revolve in the orbit represented by the dotted line. It has just completed such a revolution. It takes an appreciable, though very short, time for the impulse

to travel from 1 to 2, so that the latter has not completed its revolution but is at the point indicated in its orbit. The positions of 3, 4, 5, etc., are also indicated, and are connected by the solid line 1 to 9 that outlines the wave form from crest to crest. The height of the wave is the long diameter of a molecular orbit. The wave form advances from left to right.

When a light wave enters a glass prism as in Figure 151 the bottom of the wave encounters the glass and is retarded while the top continues to move at its initial velocity somewhat as

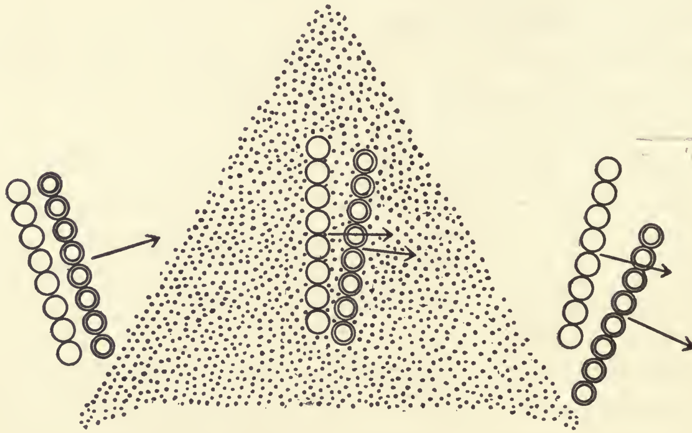


FIG. 154.—Diagram of marching men to illustrate refraction and dispersion of light.

happens in the case of a water-wave when it strikes a shelving shore. The direction of advance is therefore altered, or, as we say, the light is refracted. On leaving the prism in our diagram, it is the top of the wave that emerges first and so moves with increased rapidity, since it is now in a less dense medium, while the bottom is still retarded, and so the course of the ray of light is again altered.

Suppose a line of marching men be shown by circles (see Fig. 154). In their path is a wedge-shaped area of deep sand on an otherwise hard surface. As the line strikes the difficult going

in the sand, the men entering it are slowed up while the men still walking on the hard surface can keep their regular pace. The direction of the march will be changed, the line wheeling right somewhat. The same thing happens when the line emerges, since those men at the left of the line get out of the sand while those at the right are still plodding through it. This rough analogy may help beginners to clarify the process of refraction. The stepping of the men corresponds to the vibration of the particles in the formation of the wave of light.

Now white light is a blend of many-colored lights, each with its own specific rate of wave-motion. The violet waves are short waves, the red are long, and the intermediate colors, indigo, blue, green, yellow, orange, have increasing wave-lengths. Only the primary colors are here mentioned; there are innumerable intergrading shades each of which has its own length of wave. When a beam of such white light traveling in air passes through a glass prism, it emerges spread out into a band of color. The analogy of the marching men may again help to give some notion of why this occurs. Suppose a company is marching eight abreast. The first line is made up of short men who naturally take short steps, the next of taller men who step less often, the third line of still taller men whose steps are still longer, and so on. (This is a very unmilitary supposition, but these men are an illustration, not troops.) Again the company is tramping through the wedge-shaped area of sand. The short-stepping men will be retarded in it more than those who take long steps because they must step in it more frequently. When the company emerges, therefore, the line of very tall men will be bent out of its original course least, the line of the very short men most, and the intermediate lines will fall between these. The analogy is very crude but it may help to visualize this process of dispersion of light. The men who take long steps correspond to the long light waves like those of red light, while the men who take short steps are analogous to the short waves of such light, as the violet.

When, during a shower, the sun is shining and is fairly near the horizon, we may see a rainbow or, if in a balloon or on a mountain peak, a rain circle. The light entering the raindrops is refracted and dispersed, then totally reflected and further refracted and dispersed as it leaves the drop. In the accompanying figure (155) two of the raindrops are shown enlarged, so the course of the light can be traced. The entering light is a heavy line; the red light a light solid line, the violet light a dotted line; the intermediate colors are omitted. The color perceived is

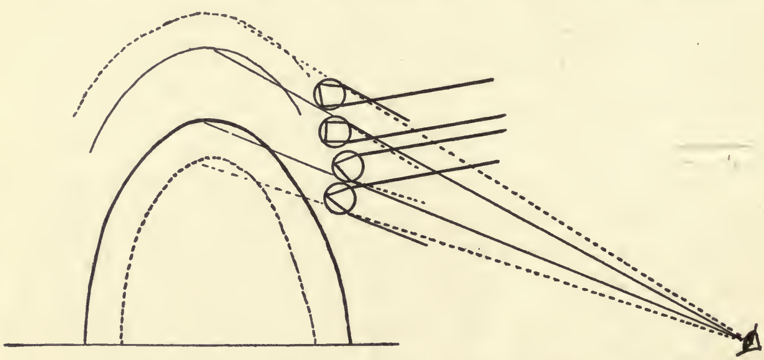


FIG. 155.—Diagram showing formation of the rainbow. Drops of water represented by the small circles are in such position that beams of light entering them are refracted and totally reflected so as to send to the eye red (solid line) and violet (dotted line) rays. The eye projects these against the sky in a primary bow and a dim outer secondary bow. Many thousands of drops are needed in similar position to complete the bow.

referred back along the line of the light entering the eye, and so is seen against the sky or clouds. The color band is a bow (or circle) because the observer is the center of curved rows of such drops that can refract and reflect the light to his eye.

If you fill a small spherical flask with water and set it on a support near a window in a darkened room so that a beam of sunlight entering through a small aperture in the curtain or shutter will strike it, a circular rainbow will appear on the shutter. This will be more evident if a sheet of white paper encircles the opening in the shutter.

CHAPTER XIII

CAMERAS AND PICTURE-MAKING

But who can paint like Nature!—JAMES THOMSON, *The Seasons*

The pinhole camera described in the preceding chapter is seldom used because it takes so long to expose the plate that any moving object produces only a blur. A lens with a large opening that admits plenty of light is used in place of the pinhole, and this lens forms an image on the sensitive plate or film. A camera, then, is a light-tight box with a lens at the center of one end and a device for holding a sensitive plate or film at the opposite end. The interior of the box is painted dull black to absorb any possible reflections from the metal mounting of the lens.

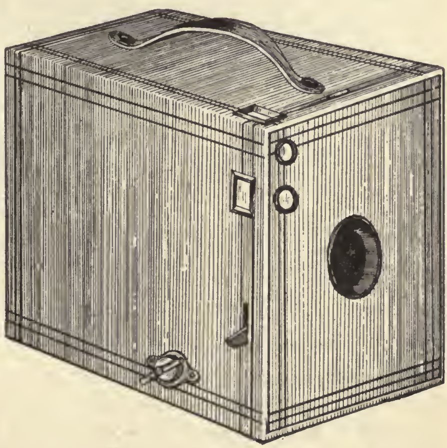


FIG. 156.—A box camera, the Brownie

In all box cameras (Fig. 156), such as the familiar Brownie No. 1 or No. 2, the lens must be what is known as a universal lens; that is, one which will give a reasonably distinct image of objects on the plate or film no matter whether they are distant or quite near. Such a lens cannot take a picture of a very close object, however. In the Brownie the near limit is 6 feet.

In all other cameras, the lens is mounted on a movable board which is connected with the front of the camera box by a bellows.

The lens may be moved nearer to, or farther from, the sensitive plate as is required to obtain a sharp image of the object. In plate cameras of this type (Fig. 157), there is a ground-glass screen covering the opening on the opposite side of the box from the lens. One throws a black cloth over his head and also

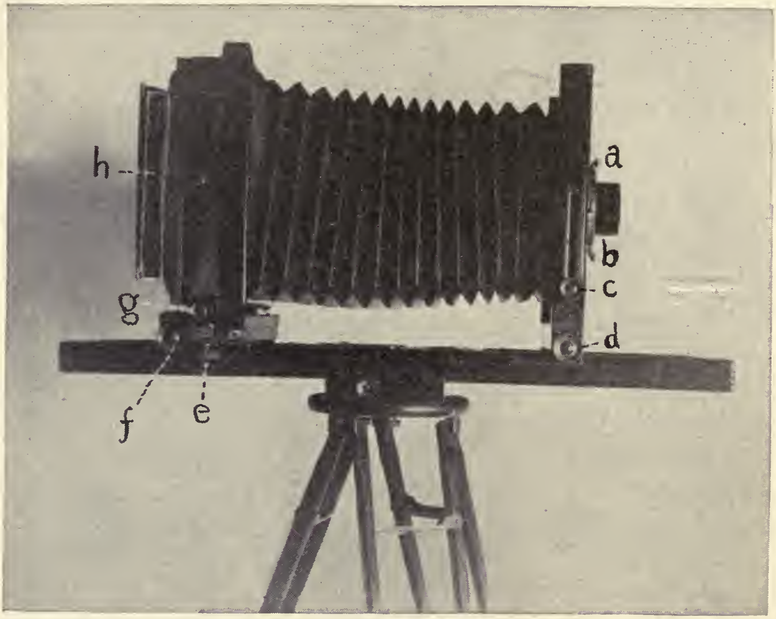


FIG. 157.—A plate camera on its tripod: (*a*) adjusts time of exposure; (*b*) adjusts size of diaphragm opening; (*c*) raises or lowers the lens; (*d*) moves front back and forth; (*e*) swings back on its vertical axis; (*f*) moves back of camera forward or backward; (*g*) swings back of camera on its horizontal axis; (*h*) plate holder.

over the camera box, as in the case of the pinhole camera above, and then moves the lens back and forth until the image seen on the ground glass is perfectly sharp. The plate is then inserted into the camera in a plate holder in the same position that the ground glass occupied when the camera was focused.

In film cameras of this type a small pointer is attached to the lens board. Under this pointer lies a fixed scale. If the

object to be photographed is 10 feet away the operator sets the pointer over the 10-foot mark on the scale; if it is 100 feet away or more, over the 100-foot mark. The position of these marks on the scale has been previously determined by the maker of the instrument by focusing on a ground glass in the position later occupied by the film.

In practically every camera, a diaphragm is provided with openings in it ranging from small to large, so that the photographer can admit through the lens a small amount of light, cutting off most of the marginal rays; or he can use a large opening admitting more light, but using more and more of the marginal rays as the opening is increased in size. The size of the diaphragm opening is usually expressed in terms of the focal length of the lens. Thus when the diaphragm openings are marked F.16, F.8, F.4.5, the symbols mean that the openings in the diaphragm are one-sixteenth, one-eighth, etc., of the focal length of the lens. This insures that, no matter what the focal lengths of the lenses may be on several cameras, the same sized pencil of light is brought to a focus on the plate when their diaphragms are set for the same opening. In some cameras the diaphragm openings are marked on the universal system (U.S.) in which each larger diaphragm is twice the *area* of the next smaller size. The U.S.16 diaphragm is just the same size as the F.16. From this it follows that U.S.4 equals F.8, U.S.8 equals F.11 approximately, U.S.16 equals F.16, U.S.32 equals F.22 approximately, and U.S.64 equals F.32.

It is furthermore evident that much more light enters the camera with a large diaphragm opening than with a small one. In fact, the amount of light varies as the squares of the diameters of the diaphragm openings. An F.8 admits four times as much light as an F.16.

Since it is the light that acts upon the plate, the length of time that the plate is exposed must depend on the size of the diaphragm used, the speed of the plate, and the intensity of the light at the time of exposure. The exposure on a bright,

sunny day will therefore be much shorter with any given diaphragm and plate than on a dull, cloudy day. One can learn by experience to judge the length of exposure under varying light conditions with different-sized diaphragms and different plates, but it will be at the expense of spoiling many plates.

It is advisable, therefore, to purchase and use an exposure meter in order to save both time and material. Cheap ones can be obtained which will indicate the exposure for any sized diaphragm under most conditions, such as time of day, season, cloudiness of the sky, nature of the object to be photographed. They are not as satisfactory under exceptional conditions, such as photographing in deep woods or indoors, as are the types in which one exposes a strip of sensitive paper to find the light intensity. The method of operation of one such may be given as typical. The exposure meter can be opened as one would take off the back of a watch, and a strip or disk of sensitive paper be laid in, after which the back is closed again. The front of such an exposure meter is shown in Figure 158. The little opening through which light gains admission to the sensitive paper is kept covered by a piece of ruby glass until one is ready to use the instrument. At one side of this opening is a sample of dark paper of fixed tint. One holds the exposure meter in the moderate shadows of the object to be taken, then turns aside the colored glass so a bit of the sensitive paper is exposed, and notes in seconds the time required for it to darken sufficiently

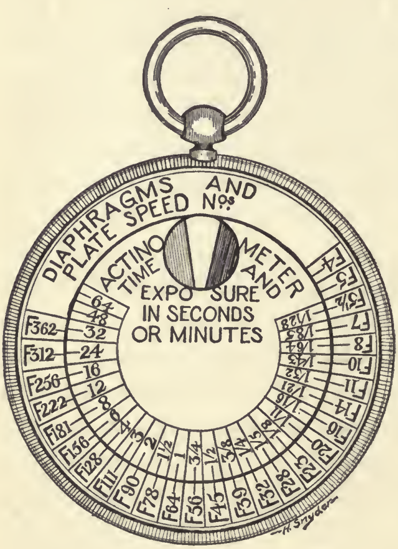


FIG. 158.—An exposure meter

to match the dark strip beside it. A circular strip of the face adjacent to the rim can be turned as the rim is rotated. On this strip are marked a series of numbers indicating diaphragm sizes and the sensitiveness of various plates. On the edge of the central disk, a series of numbers indicates seconds and fractions of a second. Accompanying the exposure meter is a booklet giving the sensitiveness of various makes of plates. Suppose we are using Cramer's instantaneous isochromatic plates. The booklet gives its speed as F.111, which means that this plate would require an exposure of one second with a diaphragm opening of F.111 under standard conditions. Suppose that it has required three seconds for the strip of sensitive paper to darken. Then set 3 on the central disk opposite F.111 on the circular strip. One may now read the exposure required for any diaphragm in seconds or fractions of a second. Thus if one is going to use an F.64 diaphragm opening he will give an exposure of one second, or if he wishes a short exposure, say one sixty-fourth of a second, he must use the F. 8 diaphragm opening. The sensitive paper rotates when the back of the instrument is turned, thus bringing a fresh bit under the opening for the next trial.

Since the enlargement of the diaphragm opening means the admission of more of the confusing marginal rays, the rule is to use as small a diaphragm opening as possible. For motionless objects one will use say an F.64 stop, and give a long exposure. But for rapidly moving objects, or even slowly moving ones, when the light is dim one must use a large stop and give a short exposure. Under such conditions a well-corrected lens must be used. The cheaper grades of cameras are therefore not made with large diaphragm openings.

The procedure in taking the picture, then, is as follows. Set the camera firmly on its tripod, and point it at the object. Open the diaphragm wide, and focus so as to get a clear image on the ground glass, the desired object at about its center. In the better cameras the lens board may be raised or lowered to facilitate such centering without moving the tripod. The back carry-

ing the ground glass swings vertically and horizontally so that one can, with these adjustments, bring all parts of the object into focus at the same time. If the object is still, diaphragm down to F.32 or F.64 and find what exposure must be given with such openings by means of the exposure meter. If the object is moving, decide how rapid the exposure must be. The nearer

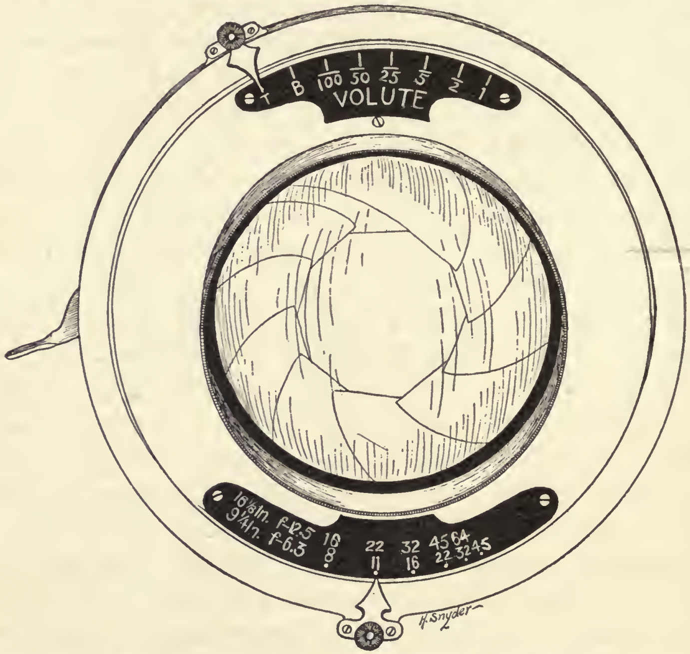


FIG. 159.—Front of camera lens to show device for setting the time (above) and the diaphragm. Shutter release is at left.

you are to a moving object, the more rapid its apparent movement will be in the image. It might require an exposure of one one-thousandth of a second to catch an unblurred image of a running athlete, while a more distant tree whose branches were swaying in the wind would need only one twenty-fifth of a second. Having decided on the time of exposure, consult the exposure meter for the size of diaphragm opening to be used. Set the diaphragm and the timing device (Fig. 159).

Be sure the diaphragm is closed. Insert the plate holder at the back of the camera and make certain it clicks into place, the ridge upon it settling into the slot provided so as to exclude the light. Draw the slide that covers the plate straight out. If it is tilted so that one corner is withdrawn before the other, light may leak in at the corner first withdrawn because the other corner prevents the little clip, operated by a spring, from closing along its entire length. Now make the exposure by pressing the release or bulb. In some cameras the release that opens and closes the shutter must be lifted to set the spring that operates it before it will work. Attend to this, if necessary, before making the exposure. Return the slide that covers the plate in the same careful way it was withdrawn.

The operation will be the same for film cameras, except that one judges the distance of the object and sets the pointer on the scale accordingly. In roll film cameras there is no slide over the film to withdraw. In reflecting cameras like the Graflex and Reflex, the image is thrown by a mirror on to a ground glass, the mirror serving to protect the film or plate from the light. One sees the image of the object up to the moment the trigger is pressed that swings the mirror out of the way and immediately releases the shutter to make the exposure (Fig. 160).

The plate or film must be taken out of the camera (except in those provided with daylight-loading devices), and developed in the darkroom. The glass plate or film used in the camera has one face covered with a thin layer of gelatine so treated that it does not dissolve readily; in this film there are imbedded minute particles of certain silver salts, usually the bromide and iodide Wherever light strikes this film, the silver salts are so affected that, in developing, the metallic silver is deposited in tiny grains, giving the area a black appearance. If you will take a plate out of its box in the darkroom, you will see that one side of it is shiny, the other dull. The shiny side is the uncovered glass, the dull side that upon which the gelatine is spread. Cover one-half of such a plate with a piece of cardboard, then bring the plate,

the half still covered, out of the darkroom and put it in strong sunlight. Very shortly the uncovered portion turns dark, in time black, but the covered portion remains yellowish white. When the plate or film is exposed in the camera the light areas of the image, such as those of the cuffs or shirt bosom in the image of a man, are affected by the light while the dark areas, such as the image of a black coat, remain largely unaffected. No image is visible on the plate, however, as the exposure is so

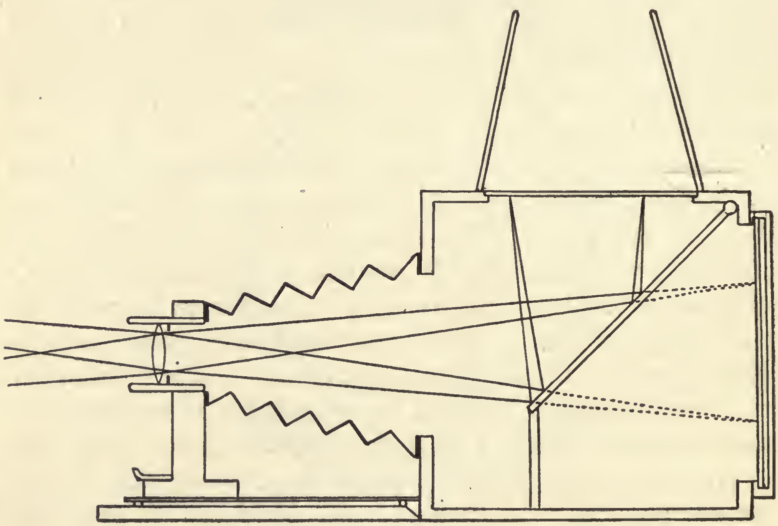


Fig. 160.—Diagram of a reflecting camera

very brief. The latent image is brought out only when the plate is chemically treated by the developer.

The sensitive plates, films, and sensitized paper that the photographer handles in order to make his negatives and print his pictures must be handled in light that will not affect these objects. As a matter of fact, all light does not affect them equally, but the rays that are at the violet end of the spectrum are the most active ones. By covering the ordinary sources of light, the window or electric light, with screens of orange and

ruby glass or paper, these rays may be kept out of the darkroom, and yet there will be left light enough for the photographer to see. One can purchase a darkroom lantern or use a ruby bulb on the electric light, or one can cover the window, the electric light, or the front of a starch box in which there is a candle, with orange and red tissue paper, or, better still, with the tough orange and ruby paper purchased from a photographic supply house. So one may use the kitchen sink or bathroom washbowl for photographic work, if one can work at night, or can shut out all light by opaque curtains during the day. The photographer has a room fitted with a sink with running water, shelves on which he can keep his apparatus, and other conveniences. This room is light-tight and is illuminated by a safe source of light.

One needs for darkroom appliances, in addition to the darkroom lamp, a hard-rubber or glass tray in which to develop plates and prints, an 8-ounce graduate and some stirring rods, a glass tank to hold the plates while they are being fixed, and a similar tank for washing them, one or more print frames of the same size as your plates, and a couple of good-sized trays for washing and fixing prints. These latter may be used in place of the glass tanks in washing and fixing plates. One may appropriate the galvanized kitchen ware, but it is well to have these usual appliances if one is going to do much developing. There are also required a bottle or large fruit jar holding two quarts or more for the fixer, as it can be used repeatedly, a small roll of absorbent cotton, and a towel that you are not afraid of staining. A small pair of scales with gram weights is needed if one is going to make his own developer and other solutions, but the beginner will prefer, probably, to buy these all ready for use (Fig. 161).

There are a number of developers used by photographers and each man has his favorite. It is well to select some one and use it persistently until you have mastered the technique of handling it. Suppose we select hydrochinone, which comes

in small tubes, five to a box. Also purchase one half-pound box of acid fixer. Be sure that the tray, fixing bath, and all apparatus to be used are washed clean. Dissolve the fixer in 32 ounces of water, and fill the fixing bath. Now dissolve the contents of a tube of the developer in 4 ounces of water in the

FIG. 161.—Some darkroom equipment. At rear a large tray for fixing or washing. At right, graduate. At its left trays for developing, the box of developing powders, with two tubes on table still farther to the left. At extreme left a plate holder with slide partly removed. At its right are print frames, one showing its back, the other with negative in place ready to print.

graduate. The tube contains at one end the developer and at the other some chemicals that speed up the rate of development. As you hold the tube in hand to read the label, the developer is at the right-hand end. Open this end first and pour the powder into the water as you stir with a glass rod. Then open the other end of the tube and pour in the chemicals while stirring. The

stirring helps to prevent the formation of lumps that will require a long time to dissolve. When the chemicals are completely dissolved, pour the developer into the tray and put in a small wad of absorbent cotton as large as a walnut. Be sure that all light is excluded except that from the darkroom light. Take the plate from its holder, handling it only by its edges. If oil from the fingers makes a finger mark on the gelatine surface, the developer will not get at the contained silver salts at this point and your negative will show the finger mark. Immerse the plate in cold water, then in the developer, which should have a temperature of about 70° Fahrenheit. The film side of the plate is to be kept up. Wipe off this side quickly but gently with the absorbent cotton wet in the developer so as to remove any adherent air bubbles. If this is not done the air bubbles may prevent the developer from reaching the silver salts, and the plate when developed will look as if dotted with pin pricks. Rock the tray to keep the developer moving over the plate. Lights and shadows should begin to appear in four or five seconds, and the clear outlines of the object in ten seconds or so. If the picture flashes up and the whole plate begins to darken at once when it is put in the developer, it has been overexposed. If the image comes very slowly and is weak, it has been underexposed. When the process of development is sufficiently advanced so that the picture begins to show clearly on the back of the plate, immerse it in water to wash off the developer and put it in the fixer. This is a solution of sodium hyposulphite together with other chemicals which tend to harden the gelatine that has been more or less softened by immersion in the developer. This "hypo" dissolves out of the gelatine film all the silver compounds that were not reduced to metallic silver in the process of development. The plate is left in the fixer until all the yellowish white has disappeared; this will take from three to ten minutes. The plate is then washed in running water for a half-hour to remove the fixer, and is stood on edge to dry. Such a plate will display dark areas corresponding to

the light areas of the object and transparent areas corresponding to the dark areas of the object; it is therefore known as the negative (Fig. 162*a*). When thoroughly dry, it is to be used to make the print or picture (Fig. 162*b*). If one is developing several plates, one after another, he should be sure to wash off from his fingers all traces of the fixer before handling the next plate, for the fixer readily spoils the developer. When through developing, put the fixer into the large-stoppered bottle to save for the next lot of plates. It will fix six dozen 4×5 plates. The developer is to be made up fresh for each new batch of plates. One tube of developer is sufficient for a dozen such plates.

The roll of films is handled in the same manner except that one holds an end of the roll in each hand and runs it through first the water and then the developer (Fig. 163). It is not necessary to wipe its surface with the cotton as the movement takes off the air bubbles. If the exposures are not accurate in the several films so that some images develop rapidly and others slowly, it will be wise to wash off the developer in the water when this fact is apparent, cut the roll into its separate films, and develop each separately. When fixed, films are pinned up to dry on a taut string like clothes on a line.

Many photographers now prefer to use the tank method of developing. A tank developer is then used, which can also be purchased in tubes. The tank is filled with the developer at proper temperature, the plates (or film) are put in and left for the time specified on the directions, when the developer is poured off and the fixer is added.

To make a print, remove the back from a print frame and lay the negative in, its uncovered side toward the light. A film must be laid on a piece of clean glass that fits the print frame. In the darkroom, take a sheet of print paper from its box or envelope and lay it on the negative, film side of the paper against that of the plate. The film side of the paper is told in the same way as in the case of the plate, though the difference in

FIG. 162*a*.—A negative

FIG. 162*b*.—A print from the negative shown above

the two sides is not as marked as in the plate. Put the back in the print frame, and fasten it in by the spring clips so it will hold the print paper firmly against the negative. Expose to the light of the electric lamp so that it will fall on the face of the negative and through it on the paper. The paper is then removed, developed, and fixed in the same way as a plate would be handled, except that it is not necessary to wipe its face. The print should be developed until it is a trifle darker than really desired as it pales a little in the fixing bath. Slide the paper into the developer rapidly and see that it is covered by the developer at once. One uses a different developer for prints than for plates usually, one that gives less contrasty results. Elon-quinol, purchased in tubes, is a good one to begin with. One tube makes up 8 ounces of developer, enough for a dozen 5×7 prints.

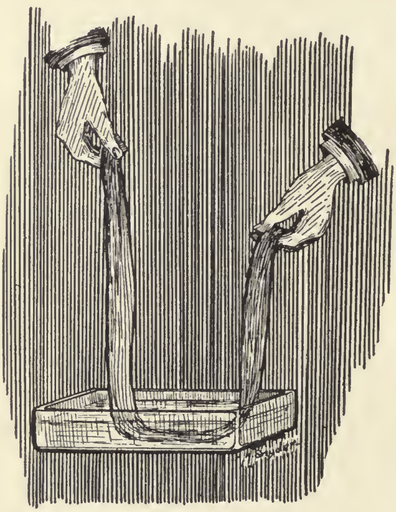


FIG. 163.—Handling the film

Just how long an exposure is to be given to make a good print depends on the brand of paper, the thickness or density of the negative, and the intensity of the light used. The print frame may be held a foot or so from a fifty-candle-power electric light with a frosted globe. Cut a sheet of print paper into several strips, and try one strip with an exposure of five seconds. If the picture comes up in the developer clearly in ten seconds or so, that exposure is about correct. If it flashes up suddenly and the strip darkens all over, the exposure is too long. If it comes up slowly and weakly, the exposure is too short. Try other strips until the exposure is correctly timed, then print the picture on the full-sized sheet. After some experience one

will judge the length of exposure needed quite accurately, without preliminary trials.

The prints are to be left in the fixer for ten minutes, then washed for twenty minutes in running water. Dry the prints, face down, on cheesecloth stretched on a wooden frame, or if glossy prints are desired, dry on a clean glass or porcelain surface. Print papers come in a variety of grades. The surface may be dull, matte, glossy, etc. The paper may be soft, normal, contrast, portrait, etc., according to the effect desired. Contrast papers are needed to give proper values in prints of weak negatives, soft papers for contrasty negatives, those in which the high lights and shadows are very strong.

FIG. 164.—A lantern slide

Lantern slides and transparencies are printed in the same fashion as paper prints, using a lantern-slide negative or transparency negative in place of the print paper. The exposure will be about one-half second at a foot from the light. Such negatives are developed in the same way as are plates. The image should be allowed barely to begin to come through on the back of the plate before it is placed in the fixing bath, as the plate needs to be thin to let the light through it readily. A mat is laid on the film face when the plate is dry, with an opening in it large enough to show the picture. This is covered with a cover glass the same size as the plate, and plate and cover glass are bound together with adhesive paper strips applied to the edges (Fig. 164). Lantern slides, transparencies, and prints may be tinted by applying to the film side by means of camel's hair brushes transparent water colors purchased for the purpose.

Sometimes a negative or a lantern slide is too thick or too thin when finished to give satisfactory results. Such may be improved by reducing or intensifying. To reduce, add a teaspoonful of a saturated cold-water solution of potassium ferricyanide to a solution of hyposulphite of soda made by adding a tablespoonful of this salt to 4 ounces of water. These proportions do not need to be exact. Put this in a tray and lay the negative in it, rocking the tray to cover all parts promptly. The operation is carried on in daylight. The more of the ferricyanide used, the more rapid the reduction. The negative is taken out when sufficiently thin, washed in running water twenty minutes, and set up to dry.

To intensify, place enough saturated cold-water solution of bichloride of mercury (poison) to cover the plate in one tray, and a similar amount of water to which ten drops of concentrated ammonia are added in a second tray. Immerse the plate in the first and leave until its surface whitens a bit. Then put it in the second tray where it will darken, especially the more opaque areas. Wash it in water for two or three minutes, and repeat the process until it is sufficiently intense. Then wash twenty minutes in running water and dry. There are many other methods of reduction and intensification that use other chemicals; these methods will be found in the books given in the Book List.

The sensitive film or plate or paper is produced by spreading evenly on these objects a thin layer of gelatine all through which there are suspended tiny particles of silver bromide and silver iodide, put there by apparently dissolving these salts in the gelatine. If the preparation is made up hot and allowed to stand and ripen before it is spread, the particles of silver salt aggregate somewhat, and the plate is coarse grained, but rapid. If it is made up cold and spread at once, the particles do not cohere, and the plate is slow, but fine grained. The slow plate, therefore, will give finer detail than a rapid one.

CHAPTER XIV

THE HOMEMADE ORCHESTRA

The man that hath no music in himself
Nor is not moved with concord of sweet sounds
Is fit for treasons, stratagems, and spoils.

—SHAKESPEARE, *Merchant of Venice.*

A modern orchestra is a very wonderful thing, with its aggregation of varied instruments gathered from the four quarters of the globe. I half close my eyes, sometimes, as I sit listening, and let my imagination change the stage setting. The immaculate gentleman who is rolling sonorous sounds from his kettle drum becomes a painted savage, his instrument a skin stretched over a hollow log; and as he pounds his war drum, his fellows brandish their cruel spears and leap in a frenzy of ecstasy in anticipation of the coming battle. The gentleman in evening attire who presides at the great organ changes to a Greek shepherd, clothed in a draped skin, who blows on his pipes, the primitive ancestor of the organ, while his sheep graze on the sun-flecked hills about him. The clarinet player I see as a squatting Indian snake-charmer who, in his gaudy robes, sways in unison with the hooded serpent before him, as he draws strange melody from his reed, the precursor of the present instrument. The French horn is the horn of a hunter who goes dashing by on his splendid horse, after a pack of dogs that are close on the heels of the fox. What a strange history each of the orchestral instruments has had! They have come down to us from the inventive genius of peoples scattered from pole to pole. Yet, while they are so very different in present form and in their evolution from many primitive types, the principles of sound on which their performance depends are few and simple. Vibrating strings or vibrating columns of air originate all the notes that are strengthened and

modified by the resonance of the body of the instrument and the air in its chambers.

Sound is due to the vibration of the body that initiates it, and these vibrations pass out as pulses into the surrounding medium. Strike a gong or bell and hold against its edge a ball made of the pith of the elderberry stem, or a tissue-paper wad suspended by a string, and the ball flies off from the bell repeatedly, impelled by the push of the oscillating particles. One can see the vibrations of a taut string, for, when plucked, it is a blur, widest usually at its central region, where it is swinging back and forth with the greatest amplitude (Fig. 165).

Sound, like light, is a form of wave-motion. The vibrating particles of the substance that carries the sound move back and forth in the same direction the sound is traveling; while,

FIG. 165.—Vibration of a taut string

in the case of light, this oscillation is transverse to the line of propagation. The sound waves move out in all directions in air, for instance, from the sounding body as concentric spheres that are alternately dense and rare (Fig. 166). Sound, therefore, like light travels from point to point in straight lines, the radii of these concentric spheres.

Its rate of propagation is relatively slow. In air it goes about 1,100 feet per second, while light in the same time travels 186,300 miles. In general this discrepancy in the rates of movement of sound and light is familiar from commonplace experiences, even if the exact difference is unknown. You see the puff of steam from a distant locomotive whistle long before you hear the toot. You see a distant woodchopper, or a section hand driving a spike into the ties, deliver a stroke and straighten up ready for the next one before you hear the sound of his blow.

The rate of propagation varies according as the substance through which the sound is traveling is more or less elastic. Sound travels through water about four times as fast as through air. It travels farther, also, the more elastic the conductor is. One can hear an approaching train or wagon when the ear is held on the rail or on the ground long before the rattle of its approach can be heard through the air. The taut string or the wire of the simple tin-can telephone (directions for making given on p. 95 of the *Field and Laboratory Guide in Physical Nature-Study*) carries the sound of the voice much farther than it could be heard through the air.

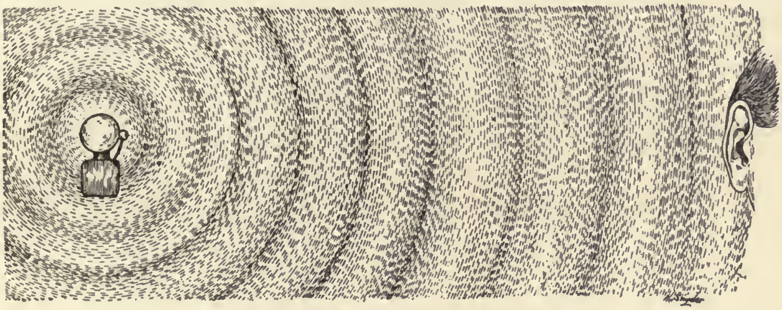


FIG. 166.—Sound waves radiating from a bell

Since sound travels in straight lines, there are sound shadows just as there are light shadows; or, in other words, an object shuts off the sound as it does the light. A block away from a noisy thoroughfare, with its clanging street cars, automobile horns, and rattling vehicles, one hears little of the hubbub, for the intervening buildings shut off the sound waves. It is true, however, that sound waves swing around the edges of an obstruction much more readily than light does, for light waves are very much smaller than are sound waves. The larger waves of deep tones can do this more readily than do the smaller waves of shrill sounds. Therefore the roar of the distant street is a hoarse roar.

Sound, too, like light, is reflected from a surface. One may focus sound with a concave mirror quite as readily as light. (See *Field and Laboratory Guide in Physical Nature-Study*,

p. 83.) When some building, or the face of a cliff, serves as a reflecting surface, the sound of the voice is sent back, as an echo, to a person listening. Do you recall the incident in *Treasure Island* in which, when the pirate crew is hunting for the buried treasure, Ben Gunn scares them away by imitating the call of old Flint, their dead but still dreaded captain? Silver, hearing the echo of Ben's voice, reassures himself and his companions by the comment that if a "spirit" does not make a shadow it stands to reason it cannot make an echo.

The violinist throws the strings of his instrument into vibration by drawing over them the bow, which takes hold of the strings because it is rosined. The banjo player or the harpist plucks the strings to cause them to vibrate. In the piano,

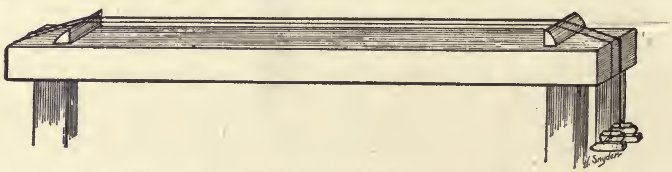


FIG. 167.—Strings stretched across a table

the string is struck by a hammer operated by pressing a key. You will notice that in harp and piano there is a string for every note emitted, and these strings vary in length, caliber, and tension. On the violin and banjo, however, there are only a few strings, but the player varies their length by pressing them down with his finger tips; only the portion between finger and bridge vibrates.

Tie one end of a string or thread to the leg of a table. Hold the free end in your left hand, pull on it, and pluck the string with your right hand so it will give out a note. Pull harder still and again pluck the string, and you will notice that the pitch of the note emitted is higher, the harder you pull. Lay the string across the table, and fasten to the free end a heavy weight like a flatiron. Support the string by a couple of strips of wood laid on edge under it near opposite sides of the table (Fig. 167). Pluck the string to get a sound and note its pitch.

Then slide one of the wooden strips nearer the other, pluck the string again, and you will find that the shorter the string, the higher the pitch of the note it gives. If now you lay a second heavier string from the table leg across the wooden strips and stretch it by another weight equal to that on the first string, you will find that the pitch of the note emitted by the heavier string is lower than that from the lighter one. Thus we learn that when a string vibrates, the note it emits is higher in proportion as the string is short, taut, and of small caliber. Therefore the strings on the bass viol are long and heavy, those on the cello are of medium length and caliber, those on the violin are short and of small diameter. In each instrument the

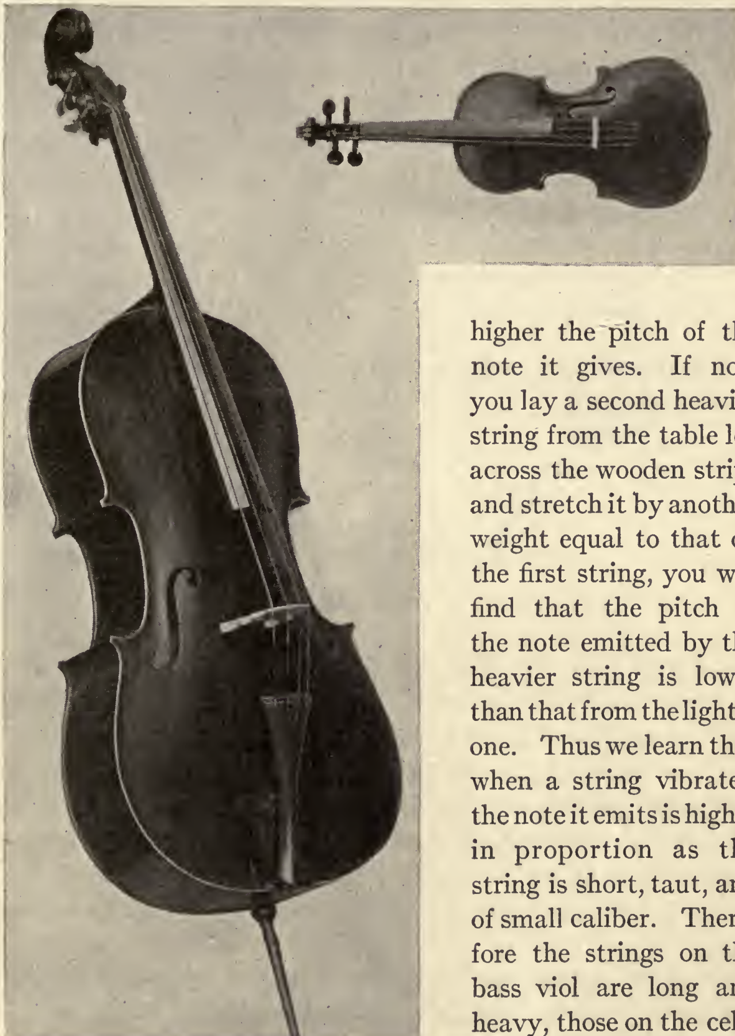


Fig. 168.—A cello and a violin. (Photo by Lyon and Healy.)

strings can be made more or less taut, and so tuned to play in any desired key (Fig. 168).

The sound produced by a vibrating string is weak. It does not hit enough air particles to start vigorous waves. If, however, it is mounted on a thin-walled box so that the vibrations of the string are imparted to the box, which presents a broad area to the air and in turn imparts its vibrations to many air particles, then the volume of sound given out is greatly increased. A watch held in the hand is scarcely heard, but place it on an empty cigar box and it sounds quite loudly. Strike an ordinary table fork on the edge of the table so as to set its tines in vibration, and the sound it gives out is scarcely audible; but press the end

FIG. 169.—Mouth end of a clarinet, showing reed

of its handle on the table, and its note is loud and clear. Not only does the wood vibrate in the violin and similar instruments, but the contained air is thrown into vibration and contributes to the volume and character of the sound. The shape of the instrument affects the quality of its notes and hence it must be skilfully made. That is one reason why the "old masters" are such costly instruments; they were made with rare skill and some luck, which even their skilful makers could seldom duplicate.

In wind instruments, it is the contained column of air that is thrown into vibration, and, pulsing back and forth, imparts its motion to the surrounding air to start the sound we hear. This column of air may be thrown into vibration by blowing across a hole in the instrument as in the flute, or by a vibrating

reed or membrane. In the clarinet, the player blows upon a thin elastic strip that lies over a slot (Fig. 169). The air pressure depresses this strip and closes the opening. But the moment the air current stops because the slot is closed, the springy tongue flies up again, opens the slot, and the current flows once more. This process is rapidly repeated, so the successive puffs of air caused by the rapidly vibrating tongue set in corresponding motion the air column within the body of the instrument. Nearly every country lad has made a similar reed instrument. He takes a hollow stalk like an oat straw or the leaf stalk of squash or pumpkin, and cuts a slanting slash in it near the node or closed end. He cuts off the other end so as to leave the crude instrument 6 or 8 inches long (see Fig. 170). Then he sticks the slot end in his mouth, covering the reed entirely, and blows to produce the note, which may be a squawk rather than a musical sound. It may be necessary to shorten the instrument a bit at a time until just the proper length is found that will give the best result.

Fig. 170.—A squawker made from an oat straw.

Just as with the string, other things being equal, the shorter the string, the higher the pitch of the note emitted, so with the vibrating air column, the shorter it is, the higher the note. Blow across the mouths of two bottles, or tubes closed at one end, one after the other, and you will note that the long bottle, or tube, gives out the lower note. This principle is well illustrated by Pan's pipes, the flute, or the whistle with movable bottom, directions for making all of which are given in the *Field and Laboratory Guide in Physical Nature-Study*. When the fife-player holds his finger tips over all the holes, the length of the column of air coincides with the length of the instrument; but when he takes his finger off one hole, the vibrating column ends at this point, reaching in the other direction to the closed end of the instrument (Fig. 171). It is true also that, of two

tubes of equal length each closed at one end, the one that has the greater diameter will give out the lower note when one blows across the open end. The pipes on the organ that produce the bass notes are long and of large diameter, while those for the high notes are short and have a small bore. So the wind blowing over the opening at the top of the chimney produces a deep note, and we say the chimney roars. This is due to the fact that the pitch of the note emitted by a vibrating string or air column depends on the rate of vibration. The shorter the string or column of air, other things being equal, the more rapidly it vibrates and the higher the note emitted; the greater

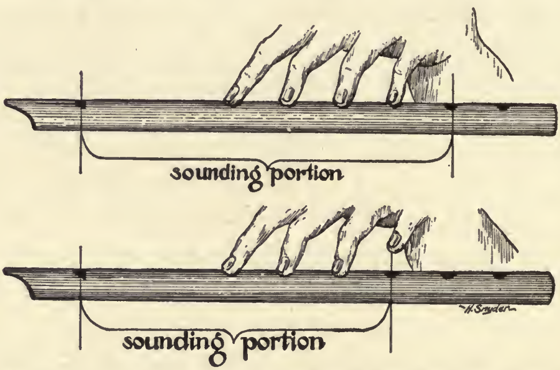


FIG. 171.—A fife, showing change of length of air column

the caliber of the string or tube, the less rapid the vibration. A long or thick string or column of air means a greater mass, and the greater the mass, the less rapidly it swings into motion.

More than that, a note of a given pitch is always produced by exactly the same number of vibrations. Thus the piano is tuned so that middle C is given off by a string vibrating at the rate of 256 vibrations per second. The C note one octave higher is produced by double the number of vibrations, and the one an octave lower by half as many. Match on the piano the pitch of a mosquito's or bee's hum and you can tell how many times per second the insect's wings are beating the air, for you can calculate the number of vibrations for any musical note.

We have chosen a musical scale in which the rate of vibration starting from middle C is as follows:

C	D	E	F	G	A	B	C
256	288	320	$341\frac{1}{3}$	384	$426\frac{2}{3}$	480	512

The intervals between the notes corresponding to these numbers of vibrations are pleasing to our ears. These numbers are in the ratio of

24	27	30	32	36	40	45	48

Or we may say that D has nine-eighths of the number of vibrations of C, E five-fourths as many, and so on, the series of fractions being

C	D	E	F	G	A	B	C
1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2

So in making Pan's pipes or the flute (see *Field and Laboratory Guide in Physical Nature-Study*, p. 95), these relations must be maintained between the lengths of the pipes used or the distances of successive holes from the mouth opening of the flute.

In making an instrument like the piano the manufacturer is confronted with a difficulty, for one may want to play on other keys besides C. Suppose, for instance, it is desired to start the scale with D or with E. Now the number of vibrations of the successive notes in the scale must bear to those of D or E the same ratio which the number of vibrations producing the notes of the C scale bear to the number of the C string. The number of vibrations needed for the notes of these new scales as compared with the number needed for the notes of the C scale is indicated below.

	C	D	E	F	G	A	B	C	D	E
When C begins the scale:	256	288	320	$341\frac{1}{3}$	384	$426\frac{2}{3}$	480	512—	576	640
When D begins the scale:		288	324	360	384	432	480	540	576—	648
When E begins the scale:			320	360	400	$426\frac{2}{3}$	480	$531\frac{1}{3}$	600	640

It is evident that there is a discrepancy between the rates of vibration needed for the notes of the C scale and the numbers needed for the D and E scales. The E note will serve for the third note of the C scale and reasonably well for the second note of the D scale, but F will not do both for the fourth note of the C scale and the third note of the D scale, so an additional key has been put into the piano at this point as a black key, which we call F sharp. Similarly, the upper C will not do for the seventh note of the D scale, and so another black key is introduced as C sharp. So it will be evident from the requirements of the E scale and others that additional black keys are required, and it has been found that we can reasonably well meet all requirements by putting in five additional black keys in each octave, and, of course, the corresponding strings. Even then you will find we have to put up with notes that do not exactly meet requirements.

The same thing is true in all instruments in which the number of vibrations is fixed by the mechanical limitations of its manufacturers. That is not true for the violin, for the length of the string and consequently the pitch of the note is determined by the pressure of the finger of the player, and this can be applied to the string anywhere. So the skilful violinist can render his notes exactly true where the pianist must be satisfied with approximately correct ones. A hundred years ago the piano used to be tuned so that certain of the notes met the requirements exactly, others only approximately. For instance, we may tune the E above middle C so it will vibrate at the rate of 320 per second and meet exactly the requirements of the C scale. Then, however, it will not meet the requirements of the second note of the D scale. Or we may tune E to 322 vibrations, when it will meet the requirements for both these scales more nearly, but for neither exactly. In the old method of tuning, certain notes sounded just right, others were distinctly unharmonious and were known as "wolves" because they howled so badly. Now the piano is tuned so that the twelve intervals in the octave

from C to C are all equal, and we have become more or less accustomed to the little discrepancies this involves so that we scarcely notice them.

When a taut string is made to vibrate by bowing it and at the same time it is lightly touched at its mid-point, it may then vibrate not only as a whole, but in each half also (Fig. 172). The note emitted by the vibrating halves is of course an octave higher than the note emitted by the whole string. Again, if the string is similarly touched at a point one-third of the distance from one end to the other, it vibrates in segments as well as in its entirety and other notes are emitted in addition to the fundamental one. Such tones are known as overtones, and in most musical instruments the quality of the sound emitted is due quite as much to the number and character of the overtones

FIG. 172.—String vibrating as a whole and in halves

and to the resonance as to the vibration of the string or air column that sets the sound going.

So the pitch of a note is determined by the rate of vibration of the body that originates it or by the wave-length, since this is determined by the former factor. The intensity of the note is determined by the amplitude of vibration of the particles of the body from which the sound comes. The greater the amplitude, the louder the sound. The quality of the sound depends on the overtones.

The human voice is produced by the vibration of two membranous flaps that lie on either side of the larynx or voice box, a cartilaginous structure at the top of the windpipe, felt in the neck as the Adam's apple (Fig. 173). In ordinary respiration these flaps are drawn to one side and lie loose. When one desires to speak, they are drawn nearly together and rendered taut, so

that their cordlike, nearly parallel edges form a slot through which the air rushes, when expelled from the lungs, and throws them into vibration. The sound thus originated passes out through the open mouth and is modified by the resonance of the air masses in mouth, nose, and throat. One can sing a note, and then by changing the tension of the cords sing another higher or lower one. By forcing the air more rapidly past the cords, they are made to vibrate more vigorously, and the note sung is made louder. If, while singing or speaking, the nose is pinched shut by the fingers so as to cut off some of the air masses that are customarily thrown into sympathetic vibration, the quality of the tone is altered. Similar changes are produced by varying positions of teeth, lips, and tongue, thus changing the shape of the resonance cavities.

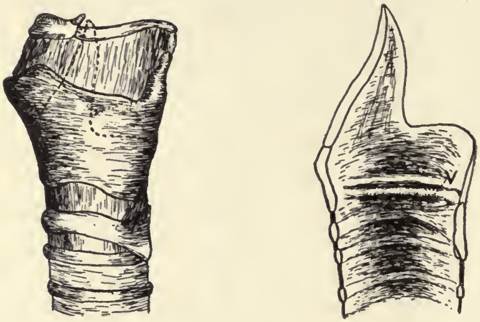


FIG. 173.—The larynx. At left, outside view; at right, sectional view of inside showing vocal cord at *V*.

One of the marvelous inventions of our own times is the phonograph, which reproduces with such remarkable fidelity the human voice, the music of the orchestra, and other sounds. Directions for making the instrument are given in the *Field and Laboratory Guide in Physical Nature-Study*. A hard-rubber disk rotates horizontally on a turntable (Fig. 174). The point

FIG. 174.—A phonograph

of a needle is placed in a spiral groove on the face of this disk. The base of the needle attaches to a diaphragm that closes the mouth of a small funnel. A tube leads from the stem of the funnel to the small end of a horn. When the disk is used to make a record, a disk of impressionable material is used in place of the hard-rubber disk. The voice, or other sound, is caught by the horn, travels down the tube, sets the membrane in vibration, and that in turn the needle. As the point presses on the disk and moves by appropriate mechanism in a spiral path, it engraves on the disk a series of tiny hills and valleys. Now, when from this disk a duplicate hard-rubber record is made and is set rotating on the turntable of the instrument, the needle, as it traverses the groove with its inequalities, is made to move exactly as it did when the voice was making the impression on the soft disk. That naturally makes the membrane vibrate, which vibration is imparted to the air and reinforced by the horn; so the sound is reproduced.

When one talks into the telephone, his voice strikes a metallic membrane and sets it in vibration. These vibrations constantly alter the intensity of an electric current that is passing through the instrument. The current of varying intensity passes through the wire to the receiver, and produces corresponding changes in the force of an electromagnet by means of which another metal disk is set to vibrating exactly in unison with that of the sending instrument. Thus the voice is reproduced so that the person at the distant end of the line hears the speaker. The method of operation of the electrical device in the instrument has been already explained.

During the war an exceedingly interesting method of locating the position of an enemy gun was employed, dependent upon the velocity of sound. Suppose that in the accompanying figure (Fig. 175), observers with accurate recording apparatus are stationed at points *a*, *b*, and *c*. Each notes the exact time at which his instrument records the arrival of the boom of the gun, and promptly telephones this time to a central station. The

officer stationed here notes these times. Suppose that the instrument at *b* registers the reception of the sound a half-second after it is received at *a* and the instrument at *c* one second after it is received at *a*. Suppose, further, that the atmospheric conditions are such that sound is traveling at the rate of 1,100 feet per second. Then evidently *b* is 550 feet and *c* 1,100 feet farther from the gun than is *a*. The officer at the central station has a diagram showing the relative positions of *a*, *b*, and *c*, and their distances from each other laid out to a scale. On this same scale he draws about *b* a circle with a radius of 550 feet and about *c* a circle with a radius of 1,100 feet. The gun is located at the center of a circle which passes through *a* and is tangent to the circles about *b* and *c*. The mathematics involved in the determination of this center is too complicated to be briefly explained. This method was found so efficient that a gun miles away could be located within 50 feet of its exact position.

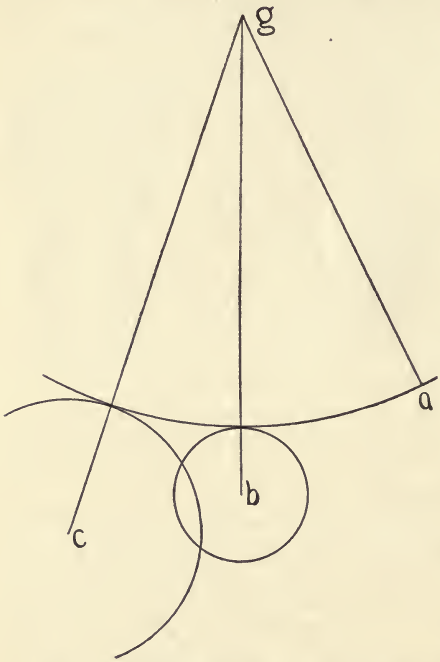


FIG. 175.—Diagram to show method of locating a gun *g*, by sound.

CHAPTER XV

SOME SIMPLE MACHINES

Give me a fulcrum on which to rest and I will move the earth.—ARCHIMEDES.

This has been aptly called an age of machinery. The food we eat, the clothing we wear, the houses we live in, the furniture that contributes to our comfort, are all largely prepared for us by machinery. We ride to school or to work in a machine, we travel by machinery, our work is largely done by the machines we direct. We farm by machinery, and machines mine our coal, furnish our light, load our ships, sweep the floor, wash the clothes, pump the water. They are our omnipresent servants; at every turn we see them at work. Yet they are all applications and combinations of three simple types of machines—the lever, the pulley, and the inclined plane—that have been in use ever since the earliest glimmerings of civilization. We think of the invention of the steam engine as a revolutionary event. Yet the savage who first discovered the use of the lever made even a greater contribution to man's advancement. It will be worth while to understand the principle of operation of these simple machines and see some of their commonplace applications.

There are one thousand and one applications of the lever about us in the home, in industrial life, and in our own bodies. Nearly every child has had experience with the teeter. A board is put over a log or saw horse, so it about balances at the middle point; then a child sits astride on either end, and they go up and down alternately as first one, then the other, gives a little shove as his feet strike the ground. This is a simple lever with its arms of equal length, and the point on which it rests, the fulcrum, at its center. If, now, one child is considerably heavier than the other, the board must be moved along on its support so that

the length of board from the heavier child to the fulcrum is shorter than that on which the lighter child sits. This same type of lever is seen in the scales or balances which the storekeeper uses to weigh his wares (Fig. 176). If you put a weight of exactly

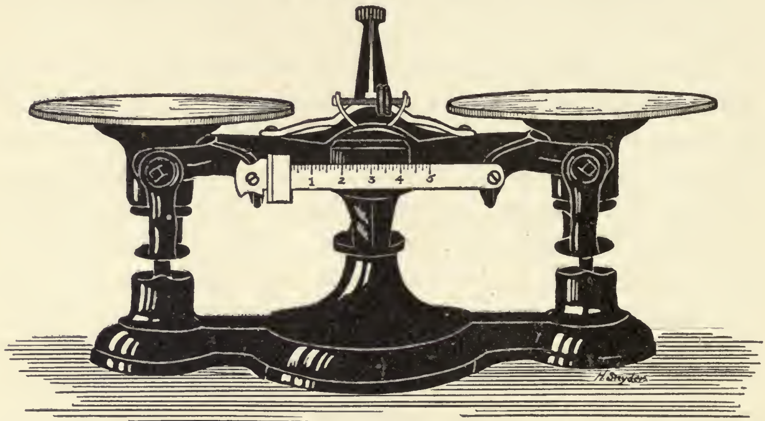


FIG. 176.—A pair of scales

one pound in one scalepan on the end of one arm of this lever, you know you have a pound of candy on the other scalepan at the end of the other equal arm when the two just balance.

FIG. 177.—The crowbar in use

If one wants to use such a lever to raise a heavy weight, say a crowbar (Fig. 177), he places the fulcrum so that the arm of the lever that is under the weight is short and the arm on the end of which he is pressing is long.

Notice, however, that he must move his end of the lever a long way down to lift up the weight a short distance. That is because one can never get more energy out of a machine than he puts into it. The weight raised, multiplied by the distance it moves, must equal the power applied, multiplied by the distance it moves. This is a law that will apply to all the machines described below. Now, in the case of the crowbar, both weight and power move through the arcs of circles whose centers are at the fulcrum, and whose radii are the weight arm and the power arm of the lever. The lengths of the weight arm and the power arm are the distances of the ends of these arms respectively from the fulcrum, but these arms are the radii. So we may say that the weight arm multiplied by the weight always equals the power arm multiplied by the power. Suppose that the board of the teeter is 11 feet long, and that it weighs 22 pounds, while the smaller boy weighs 66 pounds and the larger boy 100 pounds, and each sits one-half foot from the end of the plank. Then the fulcrum would have to be $6\frac{1}{2}$ feet from the end the smaller boy sits on, for

$$(66\times6)+(6\tfrac{1}{2}\times2)=(100\times4)+(4\tfrac{1}{2}\times2)$$
$$396+13=400+9$$
$$409=409$$

If the man in Figure 177 were pressing down on his end of the crowbar with all his weight, say 160 pounds, and this power arm on which he presses were 4 feet long, while the weight arm were 6 inches long, leaving out of consideration the weight of the bar, which may be considered as approximately balancing the element of friction, he could raise a weight of 1,080 pounds.

Sometimes it is desirable to gain speed of motion in using a lever and sacrifice mechanical advantage. Thus, in striking a blow with the fist in boxing, when the fist is suddenly shot out from the elbow, as the arm is straightened, the fist is the weight.

The bone of the forearm hinges near one end on the bone of the upper arm, the bearing serving as a fulcrum (Fig. 178). The big muscle at the back of the upper arm, attaching to the short end or power arm that projects back from the elbow joint furnishes power. When the muscle contracts, it straightens the arm, and the hand moves very rapidly. It weighs much less, however, than the equivalent of the energy that is applied by the muscle.

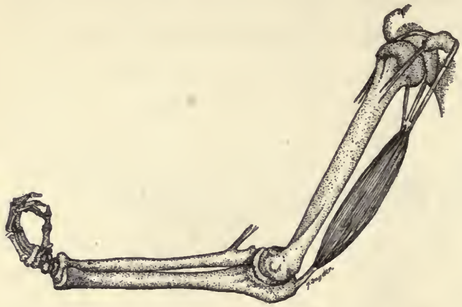


FIG. 178.—The arm showing the triceps muscle

Levers are of three sorts. Levers of the first class are those in which the fulcrum lies between the power and the weight. Levers of the second class are those in which the fulcrum is at one end, the power at the other, and the weight between. Levers of the third class have the fulcrum at one end, the weight at the other, and the power between. (See Fig. 179.) But in all cases the weight times the weight arm will equal the power

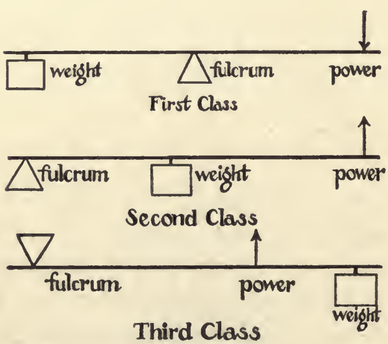


FIG. 179.—Levers of three classes

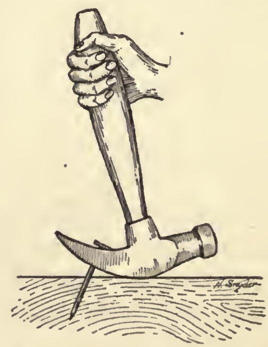


FIG. 180.—A hammer as a bent lever.

times the power arm. The law applies just as well in the case of bent levers as in those in which the weight arm and the power arm form a straight line. The hammer is a good illustration of the bent lever when it is used to pull a nail (Fig. 180). It

FIG. 181.—A wheelbarrow as a lever

will be interesting to place the various levers seen in common mechanical devices in one or the other of these classes and to calculate whether one needs little or much power, as compared with the resistance overcome, to operate such devices. A few such contrivances may be mentioned; pupils will think of many more: the lemon squeezer, wheelbarrow (Fig. 181), scissors, nutcracker, crank of a wringer or coffee mill, the forearm when the fist is brought up to the shoulder, the pump handle, etc.

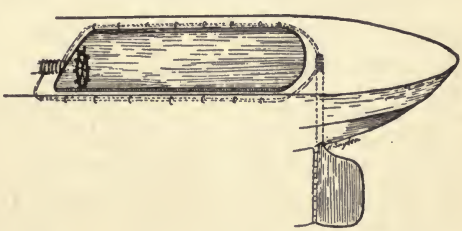


FIG. 182.—Wheel and axle used in steering a boat.

The windlass, wheel and axle, and capstan are familiar applications of the lever with which astonishing results may be accomplished. Recently in Chicago, a large brick building,

estimated to weigh 15,000 tons, was moved to its new location by two teams of horses operating capstans. The wheel and axle is commonly used in moving a rudder to steer a boat (Fig. 182).

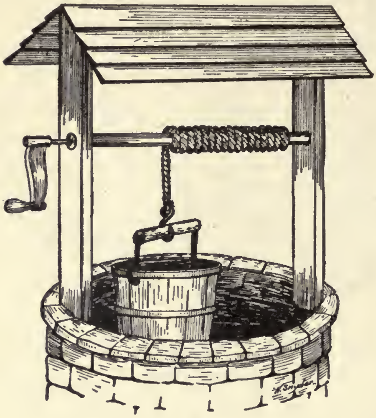


FIG. 183.—A windlass

The city child who watches the construction of a building or the country lad who sees a well dug will likely see the windlass used.

In this last contrivance, a crank is firmly fixed to a horizontal cylinder of wood or metal, the axis of which is supported on uprights (Fig. 183). A rope winds about this cylinder, bearing at its free end the bucket of earth, water, or other substances it is desired to raise. Water was drawn out of the old-fashioned well by such a windlass. A man turning the crank is applying power to one end of a lever of the first class. The fulcrum is the center of the axle, and the weight is the rope and bucket. Suppose the distance from the center of the axle to the end of the crank is 2 feet and the radius of the cylinder is 3 inches. Evidently a pressure of 10 pounds exerted to turn the crank will lift a weight of 80 pounds, leaving friction out of consideration.

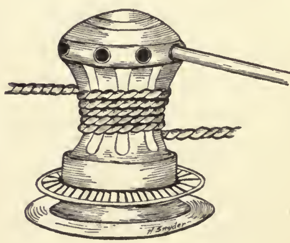


FIG. 184.—A capstan

The capstan (Fig. 184) is like the windlass except that the cylinder is set vertically, and the capstan has a bar or bars which turn in a horizontal plane, the equivalent of the crank on the windlass. When a horse attached to the end of this bar is driven around in a circle, the rope is wound on the cylinders, and the power of the horse is tremendously multiplied. Suppose

that the capstan bar is 10 feet long and the horse at its end is exerting a pull of a ton and a half; suppose, further, that the radius of the cylinder is 6 inches: then the rope winding on the cylinder is exerting a pull of 30 tons minus whatever power is used in overcoming the friction of the machine. The form of capstan in Figure 184 is much used on shipboard for raising the anchor or for similar heavy tasks.

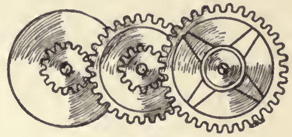


FIG. 185.—A train of gear wheels.

The wheel and axle is evidently like the windlass except that the crank attaching to the cylinder is replaced by a wheel. Several such simple machines may be combined in the train of gear wheels so as to develop immense mechanical advantage. Suppose in Figure 185 the power is applied as a weight on

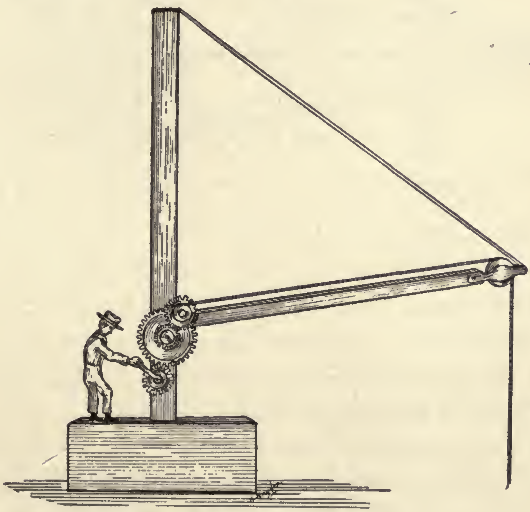


FIG. 186.—A hand derrick

a rope that winds on the axle of the right-hand wheel. This wheel has cogs that play into those of the small middle wheel which is firmly fixed to the large wheel on the same axis. The cogs of this play into those of the small left-hand wheel, which turns the large left-hand cylinder. As the weight

drops, it unwinds the rope, causing the wheels to revolve, and so winds up the rope on the large cylinder and raises the weight. Since the number of cogs on the wheels will be in proportion to their size, the mechanical advantage may be found by dividing the number of cogs on the large wheel by the number on the small. If power and weight were interchanged, then the weight would be moved rapidly, but at the expense of power applied. On a hand derrick, which combines the advantage gained from the use of a crank with that of the train of wheels attached to the crank (Fig. 186), one man may lift a weight of several tons, but his hand on the crank handle must move through a distance of many feet to raise the weight a few inches.

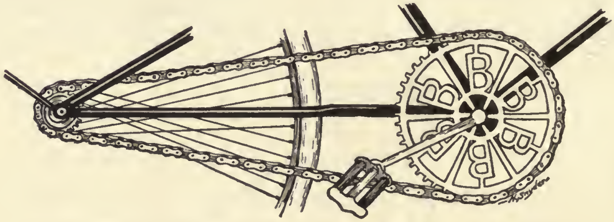


FIG. 187.—The sprocket wheel and chain on a bicycle

The sprocket wheel on the bicycle is a familiar illustration of the use of such gears (Fig. 187). The pedal shaft and axle form a windlass which increases the power applied by the pedal to the sprocket wheel. Power is lost as this plays into the small gear wheel on the hind axle with which it is connected by the chain, but speed is gained and this is desired.

The pulley is another simple machine. In its simplest form it consists of a single wheel over which a rope passes. The weight is on one end of the rope, and the power is applied to the other end. The pulley simply serves to change the direction of the application of the power, but this is often convenient. Thus, in hoisting hay into the barn loft, one can stand on the ground, put his whole weight on to the rope that passes over the pulley fastened above the window, and pull the hay up. In raising a flag on a flagpole, it is much easier to tie it to a rope that runs

through a pulley at the top of the pole, and so run it up into position, than it would be to shin up the pole and fasten it in place.

When we use two pulleys in combination, especially if each has several wheels over which the rope may run, we gain a mechanical advantage. There is shown in Figure 189 a combination of two pulleys, each with two wheels. It is evident now that the weight to be raised is supported by four strands of rope, while the one you pull on in passing over the pulley merely gives, as before, the advantage of a change in direction of the power

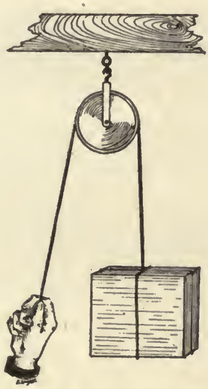


FIG. 188

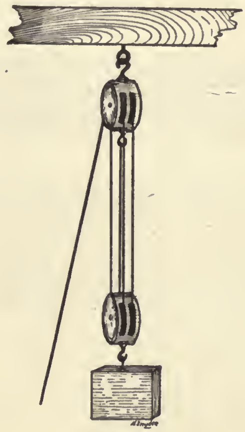


FIG. 189

FIGS. 188–89: FIG. 188.—A single-wheeled pulley. FIG. 189.—Double pulleys

applied. A fourth of the weight is borne by each strand of rope. To raise the weight a given distance, the power must move through four times that distance. Therefore, the power applied will be only one-fourth as great as the weight plus whatever is required to overcome the friction of the system. Divide, then, the weight to be raised by the number of strands of rope between the pulleys excepting the one to which the power is applied to obtain the power required to raise the weight. If there is one wheel in each pulley of such a block and tackle (as a combination of pulleys is called) there will be two strands of rope not counting the one on which the pull is exerted, and the weight raised will

be approximately twice the power applied. The power now will move two times as far as the weight.

The third simple machine found in many common appliances, either by itself or in combination with one of the foregoing, is the inclined plane. When the truck man wants to load a heavy barrel into his wagon, he often lays a plank from the rear end of the wagon to the ground and rolls the barrel up this plank instead of trying to lift it, because he can roll it up the plank so much more easily (Fig. 190). Suppose that the bed of the wagon is 3 feet above the ground and the plank 12 feet long. Suppose

Fig. 190.—Loading a barrel on to a wagon with the inclined plane

that it is a barrel of flour weighing 196 pounds that is to be loaded. This is to be raised 3 feet from the ground, but to do this the truckman applies force to it as it rolls a distance of 12 feet. Remembering now that the weight multiplied by the distance it is raised equals the power applied multiplied by the distance through which it acts, it is evident that a push of 49 pounds is sufficient to roll the barrel:

$$196 \times 3 = 49 \times 12.$$

The truckman, then, by applying power of 49 pounds plus what is needed to overcome friction, can get the barrel weighing 196 pounds into his wagon.

Suppose one is cutting a shaving from a stick of wood with a knife whose blade is six-sixteenths of an inch wide and one-sixteenth of an inch thick on the side opposite its edge; then this wedge-shaped blade is really an inclined plane. If he is bearing down on the handle of the knife with a pressure of 10 pounds, the blade is exerting a force of 60 pounds, less friction, to overcome the cohesion of the wood. So in a chisel (Fig. 191), plane blade, axe, and other cutting tools, we constantly use this simple machine.

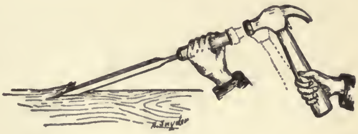


Fig. 191.—The chisel as an inclined plane.

The screw, as we use it on bolts, ordinary wood screws, on the carpenter's bench vise, the screw jack (Fig. 192), and in many other places, is really an application of the inclined plane combined with the lever. Cut a right-angled triangle out of paper, making its base 6 inches long, its altitude 1 inch. Apply the 1-inch side to a pencil and then wrap the paper about the pencil. The hypotenuse of the triangle will make a line like the thread of the screw, but this line in the triangle is a section of an inclined plane. Suppose we are turning a nut on a bolt with a wrench (see Fig. 193); the power applied on the handle moves in a circle whose radius we will say is 4 inches. Meantime the head of the bolt has moved toward the nut, a distance equal to the space between two turns of the thread. Suppose there are twenty turns of the thread per inch. The distance between threads is then one-twentieth of an inch, which is known as the pitch of the screw. The weight, therefore, has moved one-twentieth of an inch while the power has moved through the circumference of the circle with a radius of 4. The circumference of this circle is twice the radius times 3.1416, or slightly over 25 inches. The power is therefore

Fig. 192.—A screw jack.

multiplied 500 times, ignoring friction. If one were pressing, therefore, on the handle with a pressure of 20 pounds to turn the nut, the bolt head would be drawn toward the nut with a pull of 5 tons.

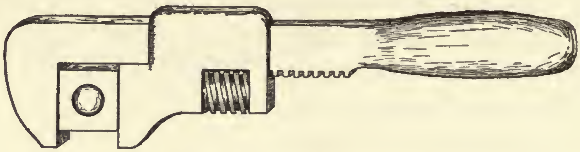


FIG. 193.—A wrench used to turn the nut on a bolt

Examine the machines that are commonly seen, the sewing machine, locomotive, automobile, typewriter, etc., and you will find they are made up of ingenious applications and combinations of these three simple machines so arranged as to accomplish the desired end. The elements that enter into any mechanical invention are few and simple, but the possible combinations and variations in the form of these elements are bewilderingly numerous.

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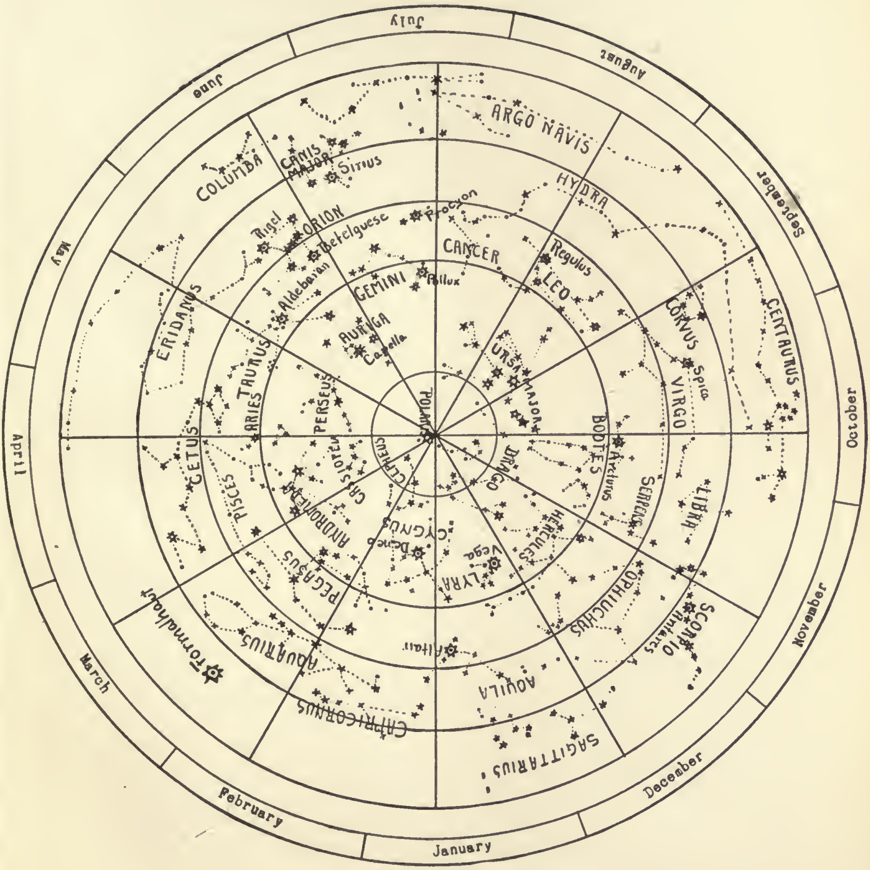

Fig. 194.—The planisphere (Part I)

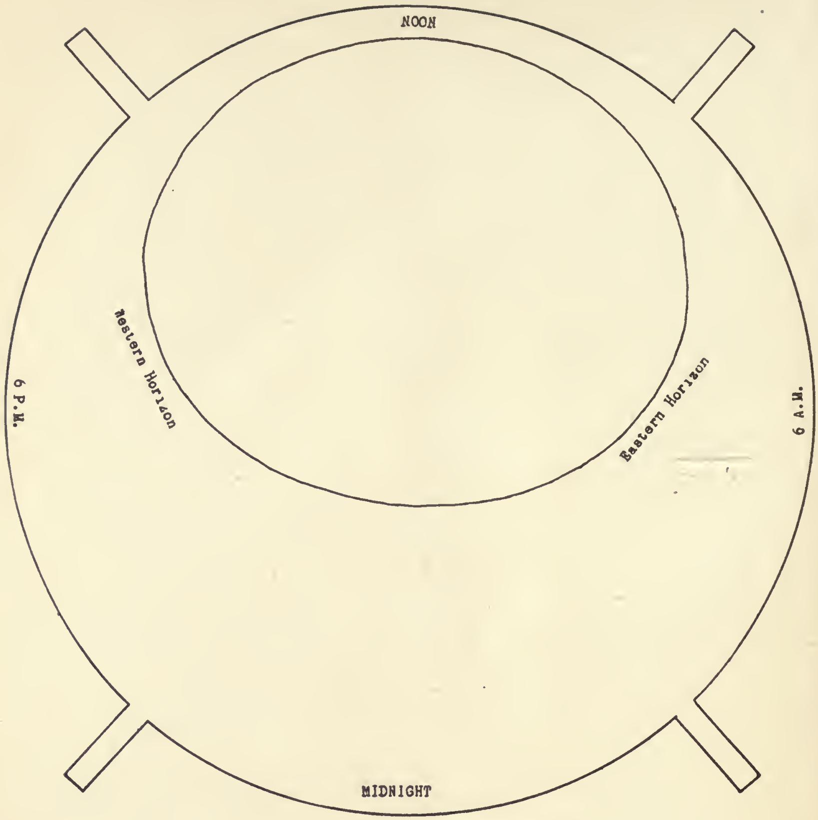

FIG. 195.—The planisphere (Part II)

To put the planisphere together paste Fig. 194 smoothly on a thin card and cut it out. Do the same for Fig. 195, but after it is pasted on the card, with a sharp penknife, cut out the ellipse from the card. Cut a second card circle the size of the circle of Fig. 195 and mark its center. Run a pin through the center of Fig. 194 and through the center of this circular card placed below Fig. 194. Lay Fig. 195 on Fig. 194, its circular edge just inside the strip bearing the names of the months. Bend the four flaps on Fig. 195 over the edge of Fig. 194 and paste them to the circular card below. Bend the pin so that its end will lie down against the circular card back and hold it in place by a piece of paper pasted over it.

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